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Simulation model for soil/vegetation/ atmosphere -interface, description of the ASTIM model

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Appendixes

1 INTRODUCTION

Present development in modelling hydrothermal processes in soil-plant-atmosphere interface form a basis to improved estimations, modelling and understanding of this complex system. Due to the heterogeneity of vegetation properties, an areal hydrological evapotranspiration model may give valuable information about processes involved. With a few measured variables, the model can be verified and calibrated to give accurate estimations of soil and vegetation properties within the system.

ASTIM (=Areal Surface Transfer Interface Model) was developed as a part of EU/LIFE project 'Development of Assesment and Monitoring Techniques at Integrated Monitoring Sites in Europe' (LIFE95/FIN/AII/EPT/378). To improve accuracy of hydrothermal knowledge and understanding of physical processes in soil-plant atmosphere system, IM site measurements were applied in an areal use of ASTIM. It was shown that the data collected within the UN/ECE ICP IM framework is useful also in advanced hydrological modelling. Combined with atmospheric information, IM site measurements gave information to calibrate the model and to verify the model results. Together with scenarios for present and changed climate (see the weather generator program CLIGEN, Carter et al. 1995) it was possible to estimate longer time scale (1990-2100) changes of the hydrological variables (evapotranspiration, soil temperature, vegetation temperature and soil moisture).

1.1 Utilization of ASTIM

ASTIM model is a one-dimensional soil/vegetation/atmosphere energy transfer model. It was developed to calculate surface fluxes, temperatures and soil moistures i.e. to model surface conditions and energy exchange from synoptic weather observations. Furthermore, it was adjusted and developed to an areal application with built in defaults for several soil/land-use classes. It solves energy balance equations at the ground and canopy levels using energy, moisture and heat equations valid at the idealized land surface. The basic Deardorff model is described in detail by Taconet (1987), Ben Mehrez (1990) and Ben Mehrez et al. (1988).

The vegetation is described by a one-layer canopy with a characteristic stomatal resistance (big leaf approach). The soil is a two-layer storage of moisture and heat characterized by conductivity, hydraulic potential, thermal conductivity, porosity etc. Atmosphere does not have any structure but is described by statistical quantities (shortwave radiation, temperature, wind speed and humidity above the canopy level, rainfall) for every hour (interpolated from daily average measurements, if needed). The atmospheric data is the main input to the program, usually received from the near by synoptical weather station or as an interpolated weather map for each day in a grid. The schematic description of the model is presented in Fig. 1.

The model calculates the energy fluxes for canopy at the top and the ground surface levels. The most important fluxes are the net radiation components in the radiation partition, evapotranspiration from the soil and from plants (dew+transpiration), ground heat flux and sensible heat flux at ground and vegetation levels. The model also calculates temperatures thus giving an important opportunity to utilize satellite or airborne measurements to calculate one free parameter in the model, for example the canopy stomatal resistance by model inversion. In Finland, the ASTIM model has been applied to estimate evapotranspiration. The appropriateness of the parameterization used to obtain leaf area index and the stomatal resistance was evaluated for a barley field located in southern Finland (Tattari et al., 1995). Furthermore, the parameterization of the model has been 'tuned' to fit the measured areal evapotranspiration (calculated by water balance method) in the Eurajoki river basin (Sucksdorffand Ottlé, 1990).

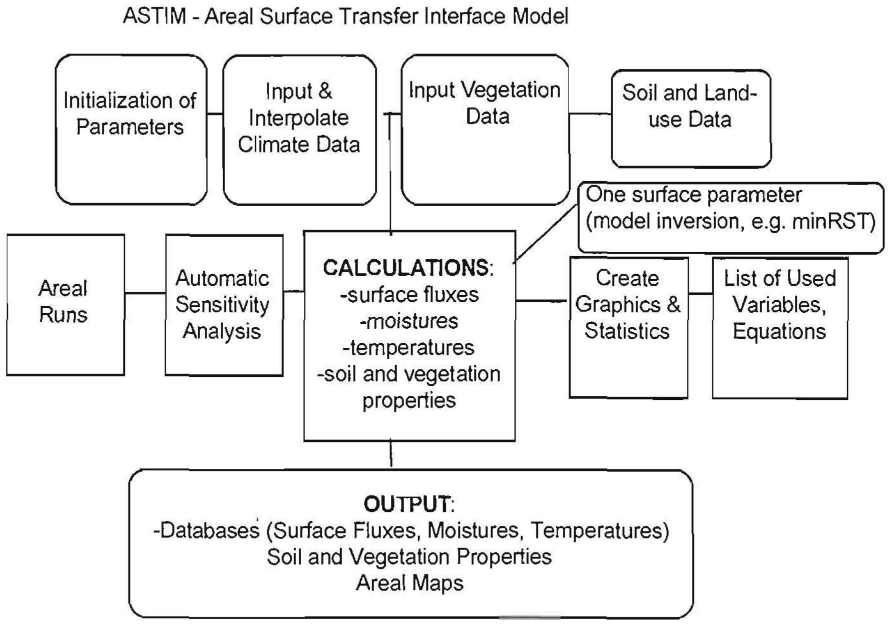

Figure 1. Schematic illustration of the ASTIM model.

Areal estimation of soil and vegetation properties is based on the soil, land-use and forest maps with a 25x25 resolution. The model output (127 output variables) can be calculated for all combined soil/land-use classes (see Appendix D). The input data includes precipitation, temperature, relative humidity, wind speed and global radiation (Appendix B). The model requires 125 input parameters, which are either measured or taken from the literature (Appendix C). Preliminary parameterizations for 58 soil/land-use classes (Appendix A) are included in the model. To run the model for a specific site, calibration and verification data are needed to adjust the model for that specific site.

1.2 Description of input data

Fig. 2 shows some of the driving variables of the model.Variables needed in the atmospheric file are temperature (average, minimum and maximum for daily files), wind speed, air humidity, global radiation and precipitation. The input data can be given as hourly or daily averages. The vegetation development information, described in a sequential vegetation development observation file, includes measured information of the vegetation properties during the year. Actual values of LAI, vegetation height and albedo are interpolated from these observations. Soil hydrothermal properties include parameterized hydraulic potential, hydraulic conductivity, heat capacity and heat conductivity curves.The dependence of soil albedo on moisture, the wintertime soil properties and the interception properties of vegetation are also needed. Basic defaults are included in the model to simplify the use of these properties. In detail, the input data is presented in chapter 4.

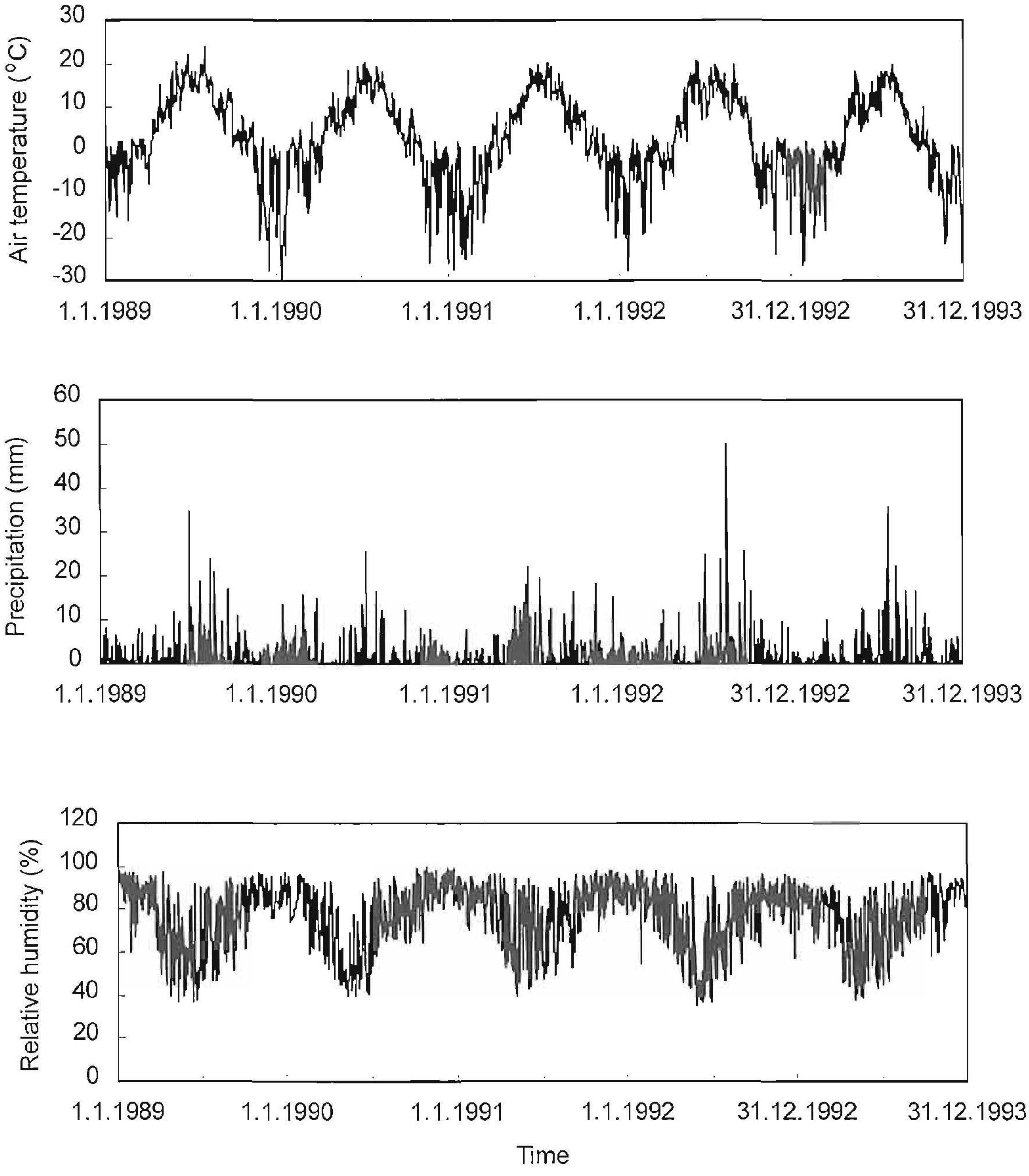

Figure 2. Examples of the input data of the model.

1.3 Description of output data

The output of ASTIM includes the temperatures of air, soil and vegetation, energy fluxes, soil moisture content, soil frost, interception and snow cover development as well as hydrothermal properties of the soil. The vegetation data includes the leaf area index, height and stomatal resistance. Surface albedo, rainfall partition and melting and freezing rates are included. The complete list of output variables is presented in Appendix E. Areal results for all soil/land-use classes may be presented separately or as an areally weighted combination. Atmospheric scenarios, here used for the years 1990-2100, combined with model results for a shorter time period, may be used to gain information about system development during the longer period. In Figs. 3-6 some examples of output results are presented.

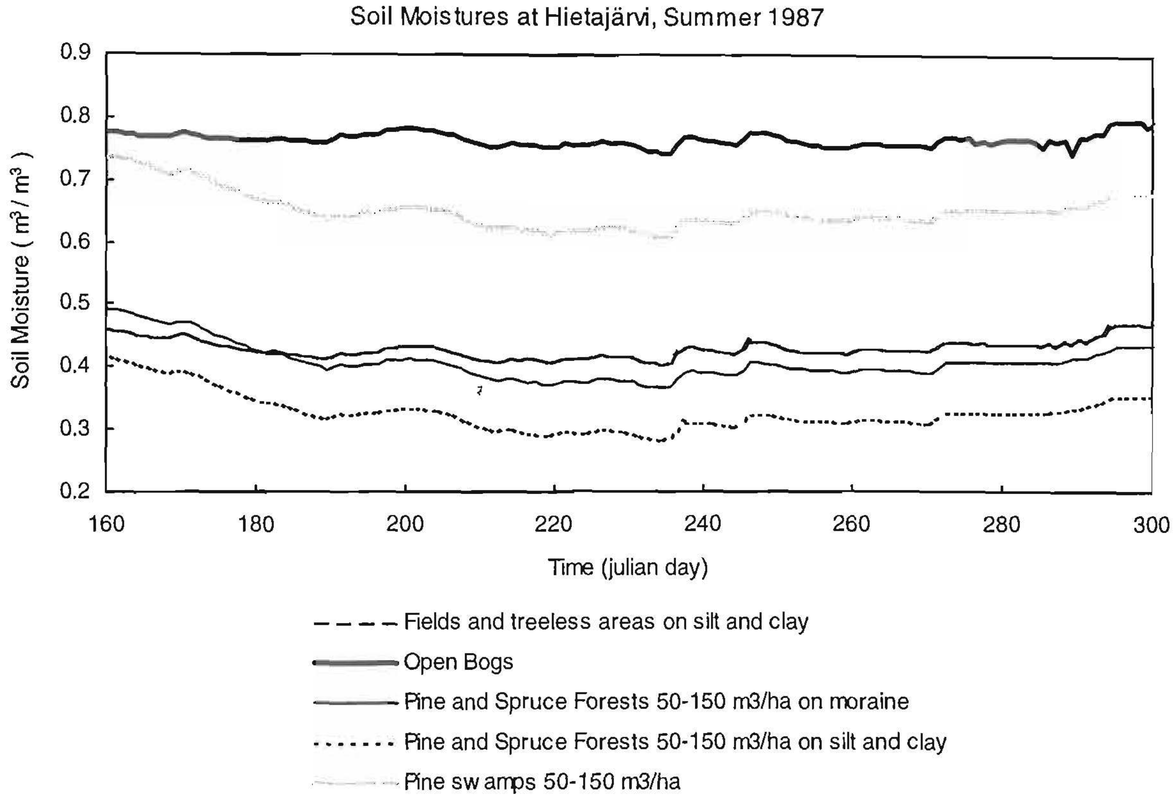

Figure 3. *Variation of soil moisture content in five different soil/land-use classes during June-October in 1987 at Hietajärvi.*

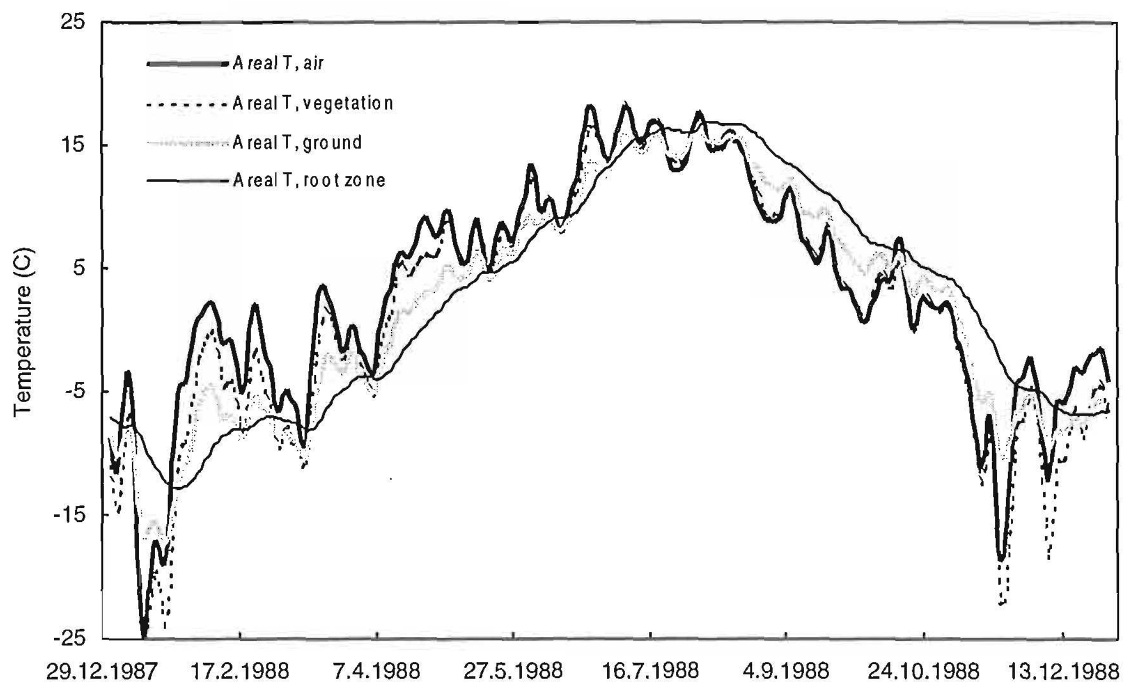

Fig ure 4. *Example of the modelled temperature (air, vegetation, soil) variation in Hietajärvi catchment.*

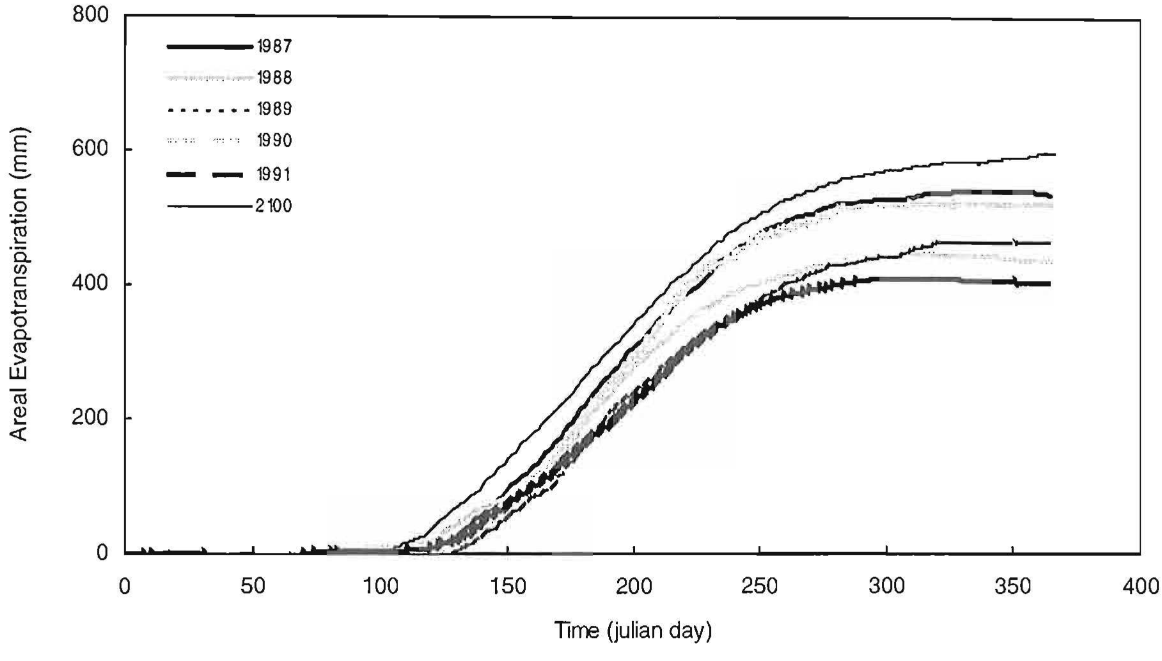

Figure 5. *Cumulative areal annual evapotranspiration in Hietajärvi catchment during 1987-1991 and an estimate for 2100 with changed climate scenario.*

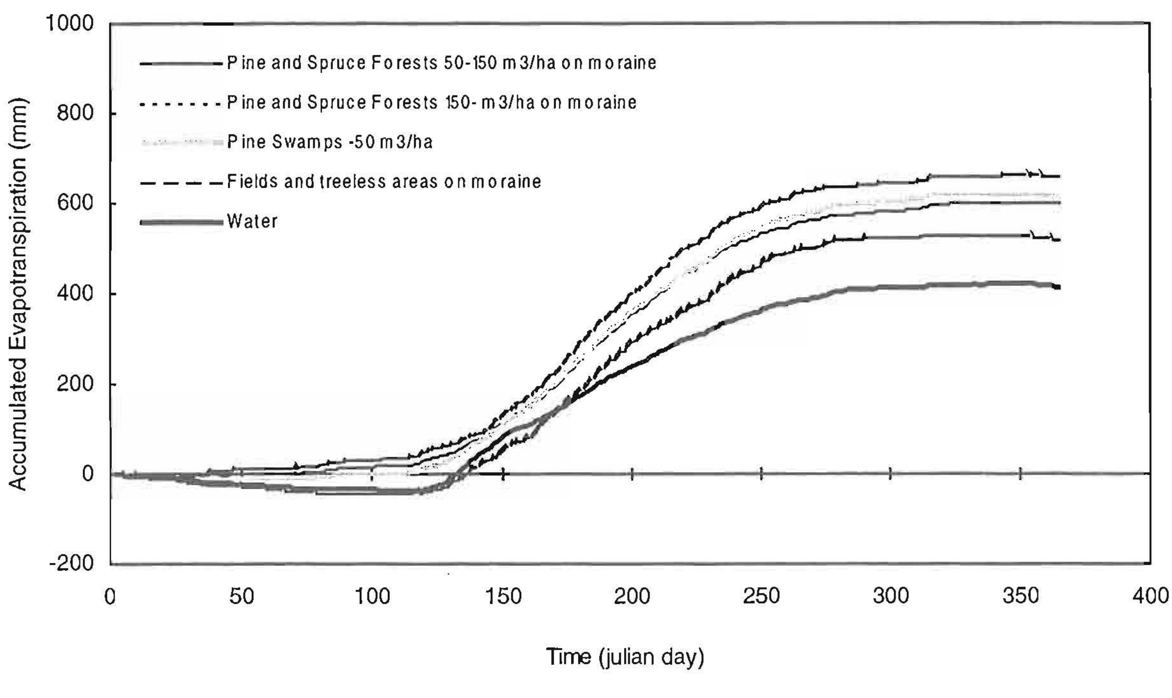

Figure 6. *Cumulative annual evapotranspiration in five different soil/land-use classes.*

2 THEORY AND STRUCTURE OF THE MODEL

2.1 Soil parameterization

The soil subscheme is used to predict the values of temperature and soil water content at two layers z_1=0 - 10 cm and z_2=0 - 120 cm. Over land covered with vegetation, the daily mean value of the soil heat flux is often one or several orders of magnitude smaller than the major terms in the energy balance. Since conduction is the main mechanism, even though convection also plays a role, the most important features of soil heat transfer can be described as a conduction phenomenon.

2.1.1 Soil hydrothermal equations

Soil heat transfer equations, based on the conservation of energy can be written

$$\rho_s c_s(z)\frac{\partial T_s(z,t)}{\partial t} = -\frac{\partial G(z,t)}{\partial z} \tag{1}$$

where ρ is soil density, c is soil specific heat capacity, T_s is soil temperature at depth z at time t and G is the soil heat flux. Heat flux can be calculated from equation (1)

$$G(z,t) = -\lambda(z)\frac{\partial T_s(z,t)}{\partial z} \tag{2}$$

where λ(z) is the heat conductivity of the soil. For the layer (0-z_s) we can write

$$\rho_s c_s(z_s)\frac{dT_s}{dt} = -\frac{G(z_s,t)-G(0,t)}{z_s} \tag{3}$$

where $c_s(z_s)$ is specific heat and T_s the average temperature of the surface layer. Daily temperature variation at the surface is assumed to be sinusoidal, whereupon the temperature at depth z at time t follows the formula

$$Ts(z,t) = T_m + \Delta T_0 e^{-z/d}\sin(\omega t - z/d) \tag{4}$$

where d and the thermal diffusion constant ν are

where T_m is daily average soil temperature, ΔT_0 is temperature amplitude, ω is 'frequency' (2π/24h) and ν is thermal diffusion constant. Equation (4) fulfils the equations (1) and (2), provided the change

$$\nu = \frac{\lambda}{\rho_s c_s} \tag{5}$$

in heat conductivity is small compared with the actual value of heat conductivity.

$$d=\sqrt{2\frac{\nu}{\omega}} \tag{6}$$

From the previous equations we can solve the temperature development at the surface $T_g = T_s(0,t)$

$$\frac{dT_g}{dt}=\left(\frac{2\omega}{\rho_g c_g \lambda_g}\right)^{1/2} G(0,t)-\omega(T_g-T_m)=-\frac{2\pi^{1/2}}{\rho_g c_g d_1}H_a-\frac{2\pi}{\tau}(T_g-T_m) \tag{7}$$

$$d_1=\sqrt{\frac{\lambda_g \tau}{\rho_g c_g}}=\sqrt{\nu_g \tau} \tag{8}$$

$$Ha=-G(0,t)=LE_g+Hs_g-Rn_g \tag{9}$$

where τ=24h and Ha is the sum of atmospheric fluxes at the ground surface. In equation (7) T_m can be replaced with T_2, if $d \gg z_2$. For the deeper layer, the assumption $T_2 \approx T_m$ is valid and we can write

$$\frac{dT_2}{dt}=-\frac{H_a}{\rho_2 c_2 d_2} \tag{10}$$

where

$$d_2=\sqrt{365\nu_2\tau} \tag{11}$$

When the model is executed, the term $\rho_g c_g d_1$ in eq. 7 is replaced, according to Deardorff (1978) with the equation

$$\rho_g c_g d_1=r'(\tau\lambda_g\rho_g c_g)^{1/2}+(1-r')(\tau\lambda_2\rho_2 c_2)^{1/2} \tag{12}$$

where r' is dependent on soil water content according to eq. 13

$$r'=0.6+0.05\frac{w_g}{w_2} \tag{13}$$

Here again, index g refers to the surface layer and index 2 to the total root zone. Time period τ=24 h.

Coefficient r' depends on the surface and root zone moisture contents and on the soil type. In addition, the thermal inertia of vegetation is assumed to be negligible.

2.1.2 Soil hydraulic properties

Water flow in the soil is assumed to be laminar. The general equations for unsaturated water flow are the continuity equation and Darcy's law. The soil water content in the surface layer and in the root zone are calculated using the continuity equation

$$\frac{\partial w}{\partial t} = -\frac{\partial q}{\partial z} \tag{14}$$

where q is the unsaturated water flow and w the soil water content.

In this model we use the two storage layer system model developed by Bernard et al. (1986)

$$\frac{\partial w_g}{\partial t} = -\frac{\partial q}{\partial z} = -\frac{q_s - q_i}{z_1} \tag{15}$$

$$q_s = E_g - Pr_g \tag{16}$$

$$q_i = -D(w)\frac{\partial w}{\partial z} = -D(w_g, w_2)\frac{w_g - w_2}{\frac{z_2 - z_1}{2}} \tag{17}$$

where q_s is the soil water flow at ground surface (evaporation E_g - precipitation Pr), q_i is the soil water flow calculated from Darcy's equation at depth $z_1 = 10$ cm, $z_2 = 120$ cm and D is hydraulic diffusivity.

Soil water content in the surface layer is:

$$\frac{\partial w_g}{\partial t} = -\frac{Etr_g - Pr_g}{z_1} - \frac{2D(w_g, w_2)}{(z_2 - z_1)z_1}(w_g - w_2) \tag{18}$$

where

$$D(w_g, w_2) = D((w_g + w_2)/2) \tag{19}$$

Correspondingly, the soil water content for the whole root zone is:

$$\frac{\partial w_2}{\partial t} = -\frac{Etr_2 - Pr_g}{z_2} \tag{20}$$

where Etr_g and Etr_2 are:

$$Etr_g = E_g + f_g \frac{LE_f}{\lambda} \frac{R_{sec}}{R_{prim}}$$

$$Etr_2 = E_g + \frac{LE_f}{\lambda} \frac{R_{sec}}{R_{prim}} \tag{21}$$

$$f_g = \left(\frac{z_1}{z_2} \right)^{\alpha_{fg}}$$

2.1.3 Surface energy flux parameterization

Energy balance at the soil surface (g) can be written:

$$Ha = -G = LE_g + H_g - Rn_g \tag{22}$$

where R_n is net radiation, LE is latent heat flux, H is sensible heat flux and G is heat flux to the ground. The net radiation at the surface is the sum of the absorbed fractions of the incoming solar radiation S_g, and of the atmospheric infrared radiation R_{ag}. Net radiation is calculated

$$Rn_g = (1 - a_g) S_g \downarrow + \epsilon_g (Rl_g - \sigma T_g^4) \tag{23}$$

$$a_g = \alpha - \beta \frac{w_g}{w_{sat}} \tag{24}$$

where the albedo a_g and the emissivity ϵ_g combine the information about soil and vegetation. α and β are soil specific constants, w_g is the surface soil water content and w_{sat} is the saturated soil water content. For Rl_g, see equation (42).

The turbulent fluxes are calculated by means of classical aerodynamical formulas. For the sensible heat flux H_g we get

$$H_g = \rho c_p C_H (T_g - T_a) \tag{25}$$

where ρ is air density, c_p is specific heat of air, T_a is air temperature and T_g soil temperature and C_H is turbulentic diffusion coefficient depending on the thermal stability of the atmosphere. The latent heat flux from the soil surface is

$$LE_g = \frac{\rho c_p}{\gamma} \alpha C_H (q_{sat}(T_g) - q_a) \tag{26}$$

In the equations (25) & (25), ρc_p is the thermal capacity of the air, γ is the psychrometric constant, C_H is the turbulent diffusion coefficient, q_a is water vapour pressure at height z_a and q_{sat} is saturation vapour pressure of the air at the ground surface temperature

$$q_{sat}(T) = 6.1078 \exp(17.27 \frac{T-273}{T-35.83}) \tag{27}$$

The coefficient α is the relative resistance of evapotranspiration at the soil surface and can be defined

$$\alpha = \min(1, \frac{E_{\lim}}{E_{pot}}) \tag{28}$$

$E_{\lim}$ is the limiting evapotranspiration, corresponding to the maximum water flux that can flow through the ground to the surface and evaporate. E_{pot} is potential evapotranspiration, which in this study is calculated by two different equations, firstly with eq. 26 presuming that $\alpha = 1$ and secondly with Shuljakovsk's formula. For $E_{\lim}$, see Chapter 3.2.

The turbulent diffusion coefficient C_H is calculated by using theories presented by Businger et al. (1971) and de Louis (1979). In a neutral situation $C_H = C_M/0.74$ where C_M is the conductivity of momentum flux. Momentum flux is calculated in following way

$$\tau = -\rho u*^2 = -\rho C_M u_a \tag{29}$$

$$u* = \frac{k}{\ln \frac{z_a}{z_0}} u_a \tag{30}$$

where ρ is air density, $u*$ is friction velocity, u_a is wind speed z_a, k=0.35 (von Karman constant) and z_0 is friction velocity.

If the situation is not neutral, turbulent conductivity depends on Richardson number Ri, which is calculated using measured values at heights 1 and 2

$$Ri = \frac{g}{\frac{T_1 + T_2}{2}} \frac{(z_2 - z_1)(T_2 - T_1)}{(u_2 - u_1)^2} \tag{31}$$

where z is height, u is wind speed, T is temperature and g is acceleration of gravity. Then flows are described using formulas

$$u* = C_d u_a \sqrt{F_M} \tag{32}$$

$$C_H = \frac{C_d^2}{0.74} u_a F_H \tag{33}$$

$$C_M = C_d^2 u_a F_M \tag{34}$$

$$C_d = \frac{k}{\ln Z} \; ; \; Z = \frac{z_a}{z_0} \tag{35}$$

In an unstable situation, when Ri is negative (temperature decreases when height increases):

$$F_M = [1 - \frac{9.4Ri}{1 + 7.4C_d^2 9.4\sqrt{Z}\sqrt{|Ri|}}] \tag{36}$$

$$F_H = [1 - \frac{9.4Ri}{1 + 5.3C_d^2 9.4\sqrt{Z}\sqrt{|Ri|}}] \tag{37}$$

In a stable situation, when Ri is positive (temperature increases when height increases):

$$F_M = F_H = [\frac{1}{1 + 4.7Ri}]^2 \tag{38}$$

2.2 Vegetation parameterization

The objective of the vegetation subscheme is to predict the foliage temperature and the specific moisture in the immediate vicinity of the leaves. A single layer of vegetation that has a negligible heat capacity is assumed.

2.2.1 Radiation partition

Parameterization of vegetation is based on the theory of Deardorff (1978). Vegetation is assumed to be a thin transparent layer, which has zero thermal inertia. Model solution is based on the simultaneous solution of energy balance equations at soil (g) and vegetation (f) surfaces. In parameterization of radiation, the most important variable is the shielding factor σ_f, which is an area-averaged shielding factor associated with the degree to which the foliage prevents short wave radiation from reaching the ground and it can vary between 0 and 1.

Shortwave radiation balance at ground surface (g) and at vegetation top (f) is

$$Rs_g = S_g\downarrow - S_g\uparrow = \frac{(1-\sigma_f)(1-a_g)}{1-\sigma_f a_g a_f} S\downarrow \tag{39}$$

$$Rs_f = \sigma_f(1-a_f)(1+a_g\frac{(1-\sigma_f)}{1-\sigma_f a_g a_f})S\downarrow \tag{40}$$

where

$$\sigma_f = 1-\exp(-0.4LAI) \tag{41}$$

where the arrows describe the direction of radiation, a is the albedo of the vegetation or the ground surface and LAI is (dry) the leaf area index.

Similarly we get for the longwave radiation

$$Rl_g = \frac{1}{X}[(1-\sigma_f)\epsilon_g(Ra\downarrow - \sigma T_g^4) + \sigma_f \epsilon_g \epsilon_f (\sigma T_f^4 - \sigma T_g^4)] \tag{42}$$

$$Rl_f = \sigma_f \epsilon_f (Ra\downarrow - \sigma T_f^4) - \frac{1}{X}\sigma_f \epsilon_g \epsilon_f \sigma (T_f^4 - T_g^4) - \frac{1}{X}(1-\sigma_f)\sigma_f(1-\epsilon_g)\epsilon_f(\sigma T_f^4 - Ra\downarrow) \tag{43}$$

where ϵ is emission coefficient for ground (g) and vegetation (f) and X is defined

$$X = 1-\sigma_f(1-\epsilon_g)(1-\epsilon_f) \tag{44}$$

Longwave radiation R_a is calculated using a formula by Brutsaert (1982) assuming that the sky is clear

$$R_a = [1.24(\frac{q_a}{T_a})]^{0.143}\sigma T_a^4 \tag{45}$$

where q_a is specific humidity of the air, T_a is air temperature and σ is the Stefan-Boltzmann constant.

2.2.2 Partition of flux quantities

Momentum flux τ at the vegetation and ground surfaces are calculated, in non-chaotic conditions, in the following way

$$\tau_f=\sigma_\alpha\tau=-\rho C_{fm}u_{af} \quad \textbf{(46)}$$

$$\tau_g=(1-\sigma_\alpha)\tau=-\rho C_{gm}u_{af} \quad \textbf{(47)}$$

$$\tau=\tau_f+\tau_g=-\rho C_M(u_a-u_{af}) \quad \textbf{(48)}$$

where σ_α is the momentum transfer coefficient for vegetation (see Eqs. 52-53), C are air turbulentic conductivities that depend on dry LAI (leaf area index) and u are wind velocities above vegetation (a) and within vegetation (af).

In the following, we present empirical equations (Thom, 1971) to calculate conductivities

$$C_{fm}=\frac{u_{af}}{9}\beta\frac{LAI}{P_d} \quad \textbf{(49)}$$

$$P_d=0.43LAI+0.42$$

$$u_{af}=u*(\sigma_\alpha\frac{P_d}{LAI}\frac{9}{\beta})^{½} \quad \textbf{(50)}$$

$$C_{gm}=(1-\sigma_\alpha)\frac{u*^2}{u_{af}} \quad \textbf{(51)}$$

where β is constant (1.1).

The friction velocity u* depends on the wind speed u_a, the ground surface roughness (friction height) z_0 and the vegetation height h. Coefficient σ_α depends on dry LAI (assumed to be independent of vegetation type)

$$\sigma_\alpha=1-\frac{0.5}{0.5+LAI}\exp(-\frac{LAI^2}{8}) \quad \textbf{(52)}$$

$$z_0 = z_0(bare\ soil) + \sigma_f \frac{h-d}{3} \tag{53}$$

where for sparse vegetation (dry LAI $\leq$ 4), d=σ_f0.66h, and for dense (dry LAI > 4), d=0.66h. For a surface covered with vegetation we can write

$$u* = C_d(u_2 - u_1)\sqrt{F_M} \tag{54}$$

$$C_d = \frac{k}{\ln Z};\ Z = \frac{z_2 - d}{z_1 - d} \tag{55}$$

For sensible heat flux we get, according to Thom (1971), Monin and Obukhov (1954) and de Louis (1979)

$$Hs_f = \rho c_p C_{fh}(T_f - T_{af}) \tag{56}$$

$$u* = \frac{k}{\ln(\frac{z_a - d}{z_0})} u_a \sqrt{F_M(Ri, \frac{z_a - d}{z_0})} \tag{57}$$

$$C_M = [\frac{k}{\ln(\frac{z_a - d}{z_0})}]^2 \frac{u_a^2}{u_a - u_{af}} F_M(Ri, \frac{z_a - d}{z_0}) \tag{58}$$

$$Hs_g = \rho c_p C_{gh}(T_g - T_{af}) \tag{59}$$

$$H = Hs_f + Hs_g = \rho c_p C_H(T_{af} - T_a) \tag{60}$$

$$C_{fh} = \frac{1}{28} u_{af} \beta \frac{LAI}{P_d} \tag{61}$$

$$C_{gh} = \frac{1}{0.74}(1 - \sigma_\alpha) \frac{u*^2}{u_{af}} \tag{62}$$

$$C_H = \frac{1}{0.74}\left[\frac{k}{\ln\frac{(z_a-d)}{z_0}}\right]^2 \frac{u_a^2}{u_a-u_{af}} F_H(R_i, \frac{z_a-d}{z_0}) \quad \textbf{(63)}$$

In these equations, H is sensible heat flux, Hs_g and Hs_f are the sensible heat fluxes at ground and vegetation surface, ρ is the air density, c_p is specific heat of air, T are the temperatures in the soil (g), in vegetation (f), and in air at level z (a), and in air within vegetation (af), C heat transfer coefficients between different layers, u_{af} is wind velocity within the vegetation. P_d is an empirical constant depending on the dry leaf area index LAI, σ_α is the radiation (energy) partition coefficient between soil and vegetation, u* is friction velocity which depends, among other things, on Richardson number R_i, surface roughness z_0, wind velocity and vegetation height h; k is von Karman constant (= 0.35), d is displacement height. F_M is a correction factor for stability.

The partition of latent heat flux happens in the following way

$$LE_f = \frac{\rho c_p}{\gamma} R_{prim} C_{fh}(q_{sat}(T_f) - q_{af}) \quad \textbf{(64)}$$

$$LE_g = \frac{\rho c_p}{\gamma} \alpha C_{gh}(q_{sat}(T_g) - q_{af}) \quad \textbf{(65)}$$

$$LE = LE_f + LE_g = \frac{\rho c_p}{\gamma} C_H(q_{af} - q_a) \quad \textbf{(66)}$$

In these equations, ρc_p is the heat capacity of air, γ is the psychrometric constant, C are turbulent conductivities of air, as before for sensible heat flux, q_{sat} is saturation water vapour pressure at vegetation (f) and ground surface (g) temperatures, q_{af} and q_a are partial water vapour pressures at heights z_{af} and z_a.

$$R_{prim} = \left(\frac{dew}{dmax}\right)^{2/3} + R_{sec}$$

$$R_{sec} = \frac{1}{\beta + C_{fh} RST}\left[1 - \left(\frac{dew}{dmax}\right)^{2/3}\right] \quad \textbf{(67)}$$

$$dew = \sigma_f \rho_{ua} Pr_f + \frac{LE_f}{\lambda} \frac{(R_{sec} - R_{prim})}{R_{prim}}$$

R_{prim} is the vegetation evapotranspiration conductivity and α is soil relative resistance of evapotranspitration (as described before), dew is water content that has condensed on leaf surfaces, dmax is the maximum amount of interception storage capacity. Exponent 2/3 and dmax are vegetation dependent constants.

RST, i.e.. canopy resistance of evapotranspiration, can be calculated by four different equations. Deardorff's (1978) RST is a function of soil moisture, solar radiation and LAI

$$RST = RS_{\min}\left[\frac{S_{\max}}{1+S} + \left(\frac{1.2w_{wilt}}{0.9w_2 + 0.1w_g}\right)^2\right]\frac{P_s}{LAI} \tag{68}$$

where S_i is incoming solar radiation, w_g is moisture of soil surface layer, w_2 is moisture of root layer, w_{wilt} is wilting point, S_{max} is maximum of solar radiation during a bright day, LAI is green LAI, P_s = 0.3LAI + 1.2 and RS_{min} is minimum resistance of evapotranspiration which depends on plant type and fenology. Figures 0.1,0.9 ja 1.2 and P_s vary depending on the vegetation type.

The parameterization of RST by the equation of Noilhan and Planton is a combination of the formulae given by Jarvis (1976) and Dickinson et al. (1986):

$$RST = RS_{\min} F_1 F_2 F_3 F_4 \tag{69}$$

where F_1 and F_4 give the dependence of RST on solar radiation and air temperature, respectively. F_3 describes the dependence on the atmospheric vapour pressure deficit and F_2 is a function of soil moisture which varies between a critical and wilting point.

Avissar's (1984) formula is:

$$RST = \frac{d_{smax}\, RS_{\min}}{d_{smin} + (d_{smax} - d_{smin})\, f_R\, f_T\, f_C\, f_V\, f_\psi} \qquad f_i = \frac{1}{1 + e^{-S(X_i - b_i)}} \tag{70}$$

where the subscript i refers to the respective environmental factors (R=radiation, T=temperature, C=minimum temperature, V= water vapour deficit and ψ=soil moisture potential), d_{smax} and d_{smin} are plant maximum and minimum conductivities, b_i is the abscissa at f_i=1/2, S_i is the slope of the curve at the point f_i=1/2 and X_i is the intensity of the factor i.

Typical values of RS_{min} for crops during growing season are 40 - 100 s/m and for fully developed crops 250 - 500 s/m.

2.2.3 Temperature and moisture

The remotely sensed surface temperature is also calculated by the model

$$R_s = \epsilon \sigma T_s^4 = \epsilon R_a - R_{nl} \qquad (71)$$

where ϵ is total emission coefficient, σ Stefan-Boltzmann constant , T_s surface temperature, R_a atmospheric radiation and R_{nl} longwave net radiation.

Moistures are calculated in the following way

$$\frac{\partial w_g}{\partial t} = \frac{Etr_g - Pr_g}{z_1} - \frac{2D(w_g, w_2)}{(z_2 - z_1)z_1}(w_g - w_2)$$
$$Etr_g = E_g + f_g \frac{LE_f}{\lambda} \frac{R_{\sec}}{R_{prim}} \qquad (72)$$

and for the deeper layer

$$\frac{\partial w_2}{\partial t} = \frac{E_g + \frac{LE_f}{\lambda} \frac{R_{\sec}}{R_{prim}} - Pr_g}{z_2} \qquad (73)$$

$$\lambda Etr = \frac{\rho c_p}{\gamma} R_{\sec}(q_{sat}(T_f) - q_{af}) \qquad (74)$$

$$Pr_g = (1 - \sigma_f \ \sigma_{ua}) \ Pr_f - Dropped \qquad (75)$$

where E_g is evaporation from the soil surface, Etr is evapotranspiration from plants. *Dropped* is the amount of wated dropped from vegetation, Pr_f is precipitation reaching the canopy, Pr_g precipitation reaching the ground surface. In equation (72), coefficient f_g depends on the root depth of vegetation.

3 MODEL PARAMETERIZATION

3.1 Soil: Heat conductivity

Heat conductivity λ depends, among other things, on soil structure, on grain size and form and soil constituent, water and air distribution in the soil. In the literature, there are several empirical equations for calculation of heat conductivity. In this work, a model by de Vries (1975) is used. However, the parameters measured by de Vries needed to be modified for Finnish conditions. According to de Vries, heat conductivity depends on soil moisture w

$$\lambda = a + b\sqrt{w} \tag{75}$$

The determination of parameters a, b depends on the availability of measured data. In the model, parameters a and b have been evaluated from reference measurements of heat conductivity (CRC, 1988). In Table 1, typical heat parameters for different constituents are presented. In Table 2, values of a and b in Eq. 76 are presented for 6 soil classes used in the model.

Table 1. Thermal properties of different constituents according to de Vries (1975).

Constituent	ρ[kg/m3]	C[J/gK]	λ[W/mK]
Quartz	2660	2.0	8.8
Other minerals	2650	2.0	2.9
Organic constituents	1300	2.5	0.25
Water	1000	4.2	0.57
Ice	920	1.9	2.2
Air	1.25	0.00125	0.025

Table 2. Values of a and b in de Vries heat conductivity equation.

Constituent	a	b
Water	0.58	0.0
Stone/Bedrock	4.0	1.0
Till	1.8	0.4
Gravel	0.3	1.0
Peat	0.25	0.65
Clay/Silt	0.3	1.0

3.2 Soil: Heat capacity of soil

The soil heat capacity equals the sum of heat capacities of soil constituents. The heat capacity of air is negligible. Accordingly

$$\rho c = (1 - w_s)(\rho c)_i + w(\rho c)_w \tag{76}$$

Index i refers to solid constituents of soil, w is volumetric water content, w_s is saturation moisture (=porosity). De Vries (1963) has proved that ρc can be related to soil moisture

$$\rho c = 4.18 * 10^3 (0.3 + w) \tag{77}$$

where the coefficient 0.3 depends on soil type and also on saturation moisture.

3.1.3 Soil hydraulic properties

The moisture potential (ψ) is a quantity representing the work that is necessary to extract water from the soil, against gravity and capillary forces. Measurements indicate that there exists a simple relation between ψ and w for each type of soil. By definition the soil diffusivity D_w is calculated by using hydraulic conductivity K and moisture potential Ψ

$$D_w = K_w \frac{\partial \psi}{\partial w} \tag{78}$$

Cosby et al (1984) presented equations for hydraulic conductivity, moisture potential and diffusivity, when saturation values are known:

$$K_w = K_s \left(\frac{w}{w_s}\right)^{2b+3} \tag{79}$$

$$\psi_w = \psi_s \left(\frac{w_s}{w}\right)^b \tag{80}$$

$$D_w = \frac{-bK_s\psi_s}{w}\left(\frac{w}{w_s}\right)^{b+3} \tag{81}$$

In these equations, subscript s refers to saturated state, w is the prevailing moisture and b is a soil dependent constant. Clapp and Hornberger (1978) and later Cosby et al. (1984) have presented parameterization for several textural classes.

In this model, the soil parameterization follows Abramopoulos et al. (1988).The following equations are valid for calculating K_w, ψ_w and D_w. The coefficients for equations are presented in Table 3.

$$K_w = \exp(aw^{-1} + b + cw + dw^2) \tag{82}$$

$$\psi_w = -\exp(Aw^{-1} + B + Cw + Dw^2) \tag{83}$$

$$D_w = -\exp[\frac{a+A}{w} + b + B + (c+C)w + (d+D)w^2][2Dw - \frac{A}{w^2} + C] \tag{84}$$

Table 3. Coefficients for parameterization by Abramopoulos (see Eqs. 83-85).

Soil	a	b	c	d	A	B	C	D
Water	0	-4.5	0	0	0	4.335	0	0
Stone	-0.042	-30.28	1.277	3.629	0.0322	13.84	0.0819	-2.612
Till	-0.642	-19.19	34.11	-20.15	0.2862	-0.278	-11.093	6.551
Gravel	-0.642	-19.19	34.11	-20.15	0.2862	-0.278	-11.093	6.551
Peat	-0.970	-28.17	55.04	-31.36	0.3793	5.635	-21.530	12.267
Clay	-1.590	-41.96	105.05	-63.55	0.9976	10.071	-46.087	27.877

3.2 Limiting evapotranspiration

Limiting evapotranspitration E_{lim} features the maximum water flow that can evaporate from a soil surface layer with a certain moisture. Soares et al. (1988) assumed constant waterflow in the 0-0.1 m surface layer and calculated limiting evapotranspiration from Darcy's law. D has been parameterized by using Abramopoulos formula

$$E_{\lim_1} = \frac{\rho L}{z} \int_{\theta_c}^{\theta_g} D_w dw \tag{85}$$

Wetzel and Chang (1987) presented the following equation for limiting evapotranspiration

$$E_{\lim_2} = \frac{\rho L}{z} \frac{(-bK_s\psi_s\theta^{-(b+3)})}{b+3} [(\frac{w_g\theta_s}{w_{max}})^{b+3} - \theta_c^{\,b+3}] \tag{86}$$

where the subscript s refers to saturated state and c to wilting point. ρ is density of water, x is thickness of the surface layer (which is humus in forests and loose surface in fields; a typical value is 10 cm), L is the latent heat of evaporation, ψ is moisture potential, w_g is the observed average moisture content and w_{max} is the measured maximum moisture content. Other quantities refer to parameters described in the previous chapter. Table 4 contains values for limiting evapotranspiration from the two parameterizations. The Soares formula was selected, as the values of Wetzel and Chang gave unreasonably high values for sandy soil.

Table 4. Values of limiting evapotranspiration as a function of soil moisture for clay and sand soil. Wilting points used for clay and sand soils are 0.25 and 0.07 respectively, and the corresponding saturated values are 0.61 and 0.40.

W_g [cm^3cm^{-3}]	E_{lim1} [Wm^{-2}]	E_{lim2} [Wm^{-2}]
0.4 (clay)	24	67
0.45 (clay)	138	226
0.50 (clay)	584	788
0.10 (sand)	17	11
0.15 (sand)	321	107
0.20 (sand)	2450	536

3.3 Interception

The amount of intercepted water was modelled using dry leaf area index DLAI, preceding shielding factor σ_f, interception wind correction factor σ_{ua} and plant and season dependent coefficient BL:

$$Intercept = \sigma_f * \sigma_{ua} * Pr_f + \frac{LE_f}{\lambda} \frac{(R_{sec} - R_{prim})}{R_{prim}}$$

$$Intercept_{\max} = BL * \sigma_f * DLAI * \sigma_{ua} \qquad (87)$$

$$\sigma_{ua} = \frac{1}{1 + au * u_{af}^2}$$

where $Intercept_{max}$ is maximum interception and au is a plant dependent constant. The fraction of rainfall left to the leaves is estimated using shielding factor and wind correction factor, assuming that the water is evaporating potentially. When the maximum interception is reached, the remaining amount of water from leaves is dropping down to ground surface. In the model, the water that doesn't intercept infiltrates into the soil. Both layers 1 and 2 are filled, and when the surface layer is saturated, the root layer is filled. When also layer 2 is full, surface runoff begins to increase. Information about the time development of rainfall in an hourly or more precise basis is a necessity to modelling the interception accurately. This fact was confirmed in a test in which, for a period of one month, the rainfall was given twice a day and once in a hour (Sucksdorff ja Ottlé, 1989). Using hourly values, the monthly cumulative evapotranspiration was 11mm higher than using 12 hour values, which is about 12% of the total monthly evapotranspiration.

3.4 Wintertime physics

The model was originally developed for summer conditions. In the present version, a simple snow cover model has been included. The processes which are considered are snow accumulation, melting/freezing, interception and compaction of snow.

Snow melting is described by

$$\frac{d(ws)}{dt} = M_{snow} \qquad (88)$$

where M_{snow} is snow melting rate and *ws* is snow water equivalent.

The soil water content in the surface layer w_g will change according to the melting rate M_g of frost

$$\frac{dw_{gwater}}{dt} = -\frac{dw_{g_F}}{dt} = \frac{M_g}{z_1} \qquad (89)$$

where

$$M_g = M_{g0} \frac{\max(w_s - 0.5 w_{g_F}, 0)}{w_s} |(T_g - 273.16)|^{\alpha_{MT}} \qquad (90)$$

For freezing soil water (ground temperature $T_g < 0°C$) we write

$$\frac{dw_{gF}}{dt} = -\frac{dw_{gwater}}{dt} = \frac{F_g}{z_1} \tag{91}$$

where F_g respectively describes the freezing of soil water

$$F_g = F_{g0} \frac{\max(w_s + 0.1 w_{gF} - 0.3 w_{gwater}, 0)}{w_s} \left|(T_g - 273.16)\right|^{\alpha_{FT}} \tag{92}$$

The deeper layer (e.g. layer 2) is in other respects alike, except that the amount of water melted in soil surface layer, dwg_{mm} is added to the root layer moisture and subtracted from the root layer frost

$$\begin{aligned} w_{2water} &= (w_2\, z_2 + z_1 dw_{gwater})/z_2 \\ w_{2F} &= (w_{2F}\, z_2 - z_1 dw_{gwater})/z_2 \end{aligned} \tag{93}$$

and the melting/freezing temperature is

$$T_{MF2} = \frac{T_2\,(z_2 - z_1) + T_g\, z_1}{z_2} \tag{94}$$

and all formulas with w_{gW} and w_{gF} are replaced by w_{2water} and w_{2F} and correspondingly T_g by T_{MF2}. The quantity dw_{gwater} describes melting and freezing in the surface layer, and is added to the root layer values.

During wintertime, also the heat capacity and conductivity equations change, as the influence of frost is included

$$\begin{aligned} \rho c_{gbare} &= a_1 (a_2 + w_{gwater} + c_1 w g_F) \\ \rho c_2 &= a_1 (a_2 + w_{2water} + c_1 w 2_F) \end{aligned} \tag{95}$$

Melting and freezing of soil and snow also influence soil temperatures

$$\Delta T_G = \frac{L_M}{\rho c_g}\left(\frac{z_1}{z_{snow}+z_1}\Delta w_{GF}z_1 + \frac{z_{snow}}{z_{snow}+z_1}\Delta ws + \frac{z_2}{z_{snow}+z_2}\Delta w_{2F}z_2 \right)$$

$$\Delta T_2 = \frac{L_M}{\rho c_2}\left(\frac{z_1}{z_{snow}+z_2}\Delta w_{GF}z_1 + \frac{z_{snow}}{z_{snow}+z_2}\Delta ws + \frac{z_2}{z_{snow}+z_2}\Delta w_{2F}z_2 \right) \quad \textbf{(96)}$$

where L_M is melting heat of snow and frost.

The compaction of snow is described as follows

$$h_{snow} = ws_F \; (A_1 + A_2 \; e^{B_1 \; AF_{snow}}) + A_3 \; e^{B_2 \; AGE_{snow}}$$

$$\rho = ws/z_{snow}$$

$$\rho c_{snow} = \rho \; C_1 \; \rho c_{snow0} \quad \textbf{(97)}$$

where h_{snow} is snow depth, ρ is snow density, AGE_{snow} is age of snow. A_1, A_2, A_3, B_1, B_2 and C_1 are constants which need to be calibrated against, for example, snow water equivalent data. AF_{snow} is amount of accumulated fallen snow and ρc_{snow} is surface heat capacity for snow cover.

For the soil surface with a snow layer, the heat capacity can be written

$$\rho c_g = \frac{z_1 \; \rho c_{gbare} + ws \; \rho c_{snow}}{z_1 + ws} \quad \textbf{(98)}$$

Ground surface albedo and vegetation albedo are calculated from Eq. (24).

$$a_g = a_1 - a_2 \frac{w_g - w_{wilt}}{w_s - w_{wilt}} \quad \textbf{(99)}$$

If there exists a snow layer, we assume that $a_1 = 0.95$ and $a_2 = 0.9$, and $a_{snow} = 0.8$. Surface albedo is then

$$a_{surf} = (1 - fr_{snow})a_g + fr_{snow}a_{snow}$$

$$fr_{snow} = 1.0 - e^{(-0.1ws)} \quad \textbf{(100)}$$

and we set $a_g = a_{surf}$ in Eqs. (23), (39) and (40). The vegetation albedo changes also due to interception of snow

$$a_{veg} = (1 - fr_{snowveg}) a_f + fr_{snowveg} a_{snow}$$
$$fr_{snowveg} = 1.0 - \exp(-0.1\, dew_{snow}) \tag{101}$$

and here again a_{veg} replaces a_f in Eqs. (39) and (40). The snow layer has an influence on surface heat conductivity and thus also on soil temperatures.

The following formulas are used to estimate the effective surface heat conductivities

$$\lambda_{gbare} = a + b\sqrt{w} + c\sqrt{w_F}$$
$$\lambda_{2bare} = a + b\sqrt{w} + c\sqrt{w_F}$$
$$\lambda_{snow} = 2.84\ \rho^2$$
$$\lambda_g = \frac{(z_1 + h_{snow})\lambda_{gbare}\lambda_{snow}}{(z_1\lambda_{snow} + h_{snow}\lambda_{gbare})} \tag{102}$$
$$\lambda_2 = \frac{(z_2 + h_{snow})\lambda_{2bare}\lambda_{snow}}{(z_2\lambda_{snow} + h_{snow}\lambda_{2bare}}.$$

As the temporal development of the surface layer of the soil was, as in Eq. (13), dependent on both layers 1 and 2, also soil frost will influence the time development of T_g, so

$$r' = 0.6 + 0.05\frac{w_g + c_1 w_{gF}}{w_2 + c_1 w_{2F}}. \tag{103}$$

Moreover, moisture potential changes when soil frost formation occurs. In all formulas for hydraulic potential, w_g and w_2 are replaced by w_{g*} and w_{2*}

.

$$w_{g*} = \max\left(\frac{w_g w_s}{\max((w_s - w_{gF}, w_{wilt})}, 0.01\right),$$
$$w_{2*} = \max\left(\frac{w_2 w_s}{\max((w_s - w_{2F}), w_{wilt})}, 0.01\right). \tag{104}$$

3.5 Annual development of vegetation

Vegetation properties like height, leaf area index, albedo are calculated for each soil/vegetation class during the growing season from t_1 to t_2

$$LAI(z) = LAI_0(z)\left(\frac{t-t_{1LAI}}{t_{2LAI}-t_{1LAI}}\right)^{\alpha_{LAI}}\left(\frac{t_{2LAI}-t}{t_{2LAI}-t_{1LAI}}\right)^{\beta_{LAI}}$$

$$DLAI(z) = DLAI_0(z)\left(\frac{t-t_{1DLAI}}{t_{2DLAI}-t_{1DLAI}}\right)^{\alpha_{DLAI}}\left(\frac{t_{2DLAI}-t}{t_{2DLAI}-t_{1DLAI}}\right)^{\beta_{DLAI}} \qquad \textbf{(105)}$$

$$h(z) = h_0(z)\left(\frac{t-t_{1h}}{t_{2h}-t_{1h}}\right)^{\alpha_h}\left(\frac{t_{2h}-t}{t_{2h}-t_{1h}}\right)^{\beta_h}$$

where LAI_0, $DLAI_0$, h_0, α_x, β_x describe the vegetation and t_{1x}, t_{2x} the start and end times of the development within the vegetation zones. For green plants, outside growing season LAI=0, DLAI=0 and h=0. For other plants $t_1<0$ and $t_2>365+\mathrm{dleap}$ where dleap is 1 for leap years, 0 for other years. If the development of vegetation is based on thermal sum, we use the formula

$$t=365\frac{Ta_{sum}}{Ta_{msum}} \qquad \textbf{(106)}$$

and if it is based on the radiation sum, we use

$$t=365\frac{S_{sum}}{S_{msum}}. \qquad \textbf{(107)}$$

3.6 Sensitivity of the model to some selected parameters

The sensitivity of the model to some selected model parameters was analysed using data from a barley field in Vihti (Tattari et al., 1995). The parameters selected for the test are: σ_f, λ, Rs_{min}, LAI, plant height, E_{lim}, and initial temperature of the soil in the surface and root layers. The test runs were made during summer 1991 for a period of one month. In the Table 5 the initial values of the used parameters are shown. Synoptic parameters (wind speed, global radiation, air temperature, relative humidity and rainfall) were measured at every three hours. Table 6 shows the changes in the output when the above mentioned parameter changes have been made.

To increase LAI increases the evaporative area of the vegetation and the shielding factor (σ_f) Shielding further influences the radiation partition as well as interception properties. Table 6 shows that LAI and σ_f have the greatest impacts on energy balance components. As expected, G is mostly dependent on σ_f, t_2 and on the constants in deVries equation (76).

Table 5. Base run parameters for clay soil.

Parameter	Unit	Value	Comments
z_1	mm	100	Surface layer thickness
z_2	mm	1200	Root layer thickness
w_{wilt}	vol-%	0.10	Wilting point
w_s	vol-%	0.45	Measured maximum moisture
ψ_s	m	-3.1	Moisture potential at saturation
σ_f	-	0.8	Shielding factor in eq. 41
K_s	ms^{-1}	$4.8\ 10^{-9}$	Saturated hydraulic conductivity
b	-	11.55	Constant in eqs. 78-80
w_g	vol-%	0.27	Initial moisture content in layer z_1
w_2	vol-%	0.36	Initial moisture content in layer z_2
t_2	K	288	Initial temperature in layer z_2
ϵ_g	-	0.98	Soil emissivity
ϵ_f	-	0.98	Vegetation emissivity
RST_{min}	sm^{-1}	160	Minimum stomatal resistance of evapotranspiration
LAI	m^3m^{-3}	4	Leaf area index
h	m	1	Vegetation height
λ	$W[mK]^{-1}$		$\lambda=-0.198+1.389\sqrt{w}$ (see eq. 74)

Table 6. Effects of change of some selected parameters on daily average energy balance components. R_n is net radiation, H is sensible heat flux, G is heat flux to the soil and Etr is evapotranspiration ot the test period of one month in summer 1991.

Changed parameter	R_n Wm^{-2}	H Wm^{-2}	Etr Wm^{-2}	G Wm^{-2}
Base run	154	83	64	7
$h = 0.5$ m	154	83	65	7
$h = 1.5$ m	157	89	64	4
$LAI = 2\ m^2m^{-2}$	158	98	54	5
$LAI = 6\ m^2m^{-2}$	152	76	72	5
$t_2 = 290$ K	154	86	65	3
$t_2 = 284$ K	156	76	65	16
$RS_{min} = 80\ sm^{-1}$	155	72	77	6
$RS_{min} = 240\ sm^{-1}$	154	90	57	7
$\sigma_f = 0.33$	133	50	59	23
$\sigma_f = 0.91$	151	84	64	3
deVries Eq. (74) $a = -0.099$ $b = 0.694$	154	84	65	5
$a = -0.594$ $b = 4.167$	155	80	64	10

4 USER MANUAL

4.1 Installation

The program is made for FORTRAN77, for MS-Fortran in PC's, but it should be possible to run it in any computer with a close-to-standard FORTRAN77 with minor modifications (e.g. file handling, graphics, memory use). The computer should have a 80386 (or better) processor, at least 8 MB of memory available and at least some 2 MB of free file space.

When running, the program first calculates a 'base run', a default to which the later runs can be compared. After the base run, the user is given a menu-driven toolbox to analyze the behaviour of the model under parameter changes. Most graphics in the model are available on a hourly and a daily basis, some also on a period level. A short run-report is available to quickly view the run results.

A simple windows system was installed to simplify the use of the menus. The memory capacity available limits the number of windows in use and their size, but as the windows are compressed in memory, there can be several windows visible on the screen at a time. To facilitate the use of the model there are special selection windows to pick up a word or a 'topic' from a table or a group of topics. This simplifies menu use like selecting the graph to plot, plot options etc. Quick search of keyed character on the window facilitates the use of long lists of topics. Appendix F presents a short list of related utilities to study model results.

4.2 Interface menu-structure

The main menus of ASTIM SF-1.23 are the manual and the auto-variation selection menus, from which the user selects the changes, runs and screening of the results. The menus are mostly self-explanatory, so by using the model they will become familiar. In general, selecting zero is a default to quit, cancel or select default activity. If any other value is required it will be noted.

MANUAL	
0 - Quit running	
1 - Change of model variables	A
2 - Simulation run	
3 - Show graphics	B
4 - Show statistics	C
5 - Show changes	D
6 - Write results	E
7 - MSDOS and model utilities	F
8 - Pixel selection	G
9 - => AUTO VARIATION mode	

MANUAL MODE is the default mode. This mode is used to run the model with selected parameter settings.The time series of output variables can be displayd on the screen or can be stored in a separate file. The basic statistics are available in this option.

AUTO-VARIATION	
0 - Quit	
1 - Change model variables	A
2 - Variation running	H
3 - Spectrum view	J
4 - Statistics view	K
5 - Evaluation View	L
6 - Table Variations	M
7 - Write results	N
8 - MSDOS and model utilities	F
9 - => MANUAL mode	

AUTO-VARIATION mode is useful when studying the sensitivity of the output variables to model parameters and input variables. The sensitivity analysis is based on three different techniques: fixed shift mode, spectrum mode and table variation mode. In the fixed shift mode, each selected (by INFLAG) input variable is changed by a fixed percentage from a reference value. In the spectrum mode one selected variable varies around its base value. In both modes the results can be shown graphically. In the table variation mode the user gives a list of variables and their variation in a file.

```
                                                    A
CHANGE MODEL SETUP and PARAMETERS

 0 - Quit (Goto Menu)
 1 - Change base coefficients
 2 - *** Future option selection ***
 3 - Change graphics output setup
 4 - Change statistics output setup
 5 - Change variation parameters
 6 - Change write type, current:       graphics
 7 - Change run defaults
 8 - Change atmospheric input
 9 - Change RSTO / lambda / K,Psi selections
```

CHANGE MODEL VARIABLES (A) option is used when the user prefers to run the model with a different setup of model choises, parameters or run flags. The output can be targeted to several devices and/or to a file. The variable changes for a fixed variation mode can be selected here.
Run defaults like time period, site, LAI calculation mode with an annual LAI calculation type (time, thermal, radiation or thermal+radiation), quality status filter in calculations, hydrothermal and stomatal resistance options, quickstore of results to files and IO sources and destinations can be selected here.

```
                                                         B
GRAPHICAL REVIEW / ONE RUN

 SELECT FUNCTION / plot of:
 00 - Quit                   99 - Change mode
 90 - Combination            80 - Function
 01 = Ebal / canopy+ground   04 = Ta&Ts&Tgave&T2
 11 = Ebal / canopy          41 = Ta/TZ
 12 = Ebal / ground          42 = TF
 20 = Sglob                  43 = Ts/Tem
 21 = Et/lebow               44 = Tgave
 22 = Rn                     45 = T2
 23 = G                      46 = Taf-Ta
 24 = H                      47 = LAI
 25 = Et,lev2,leg2           48 = hc
 26 = rain                   49 = alb
 27 = RHz                    50 = glg & gl2
 28 = Uz                     51 = wg & w2
 29 = Precip
 31 = ELIMWG                 52 = Pfg & Pf2
 32 = ELIM1,ELIM3            53 = dew*1000
 33 = DIF1,DIF3              54 = alfa
 34 = DIF                    55 = RSTO
```

GRAPHICAL REVIEW/ONE RUN (B) is an option to plot one or more variables on the screen. From the CHANGE PLOT PARAMETERS option one can change the mode of graphics. Special modes are the modulation mode where several days can be plotted on top of each other or in separate pictures.The calculated values can be compared against the measured values or studied separately. Any observed or calculated value can be used as an x-coordinate thus allowing correlation studies (see chapter 4.4). The zooming option is useful when studying small parts of the graph.

```
CHANGE GRAPHICS MODE / ONE RUN GRAPHS

SELECT FUNCTION:

0 = Quit
1 = Day / Hour / Pickup mode       : HOUR
          -> Hour to pick :  14
2 = Modulo time (time split, days) :   .00
3 = Modulo mode                    : OVER
4 = Display mode (comp/separ)      : COMP
5 = X-axis variable                : TIME
6 = Sign/Line/Histo/Array/Hi&arr   : LINE
7 = Line output mode               : LINE ->
8 = Plot cuts  [MIN,MAX]           : -.10000E+11  .10000E+11
9 = Status filter mode             : NO
          -> Accept (3210)         : 0000
A = Time quadrats & sign mode      : NORMAL
```

CHANGE GRAPHICS MODE FOR ONE RUN GRAPHS -option allows special graphical properties like (1) hour, (2) day and (3) hour pickup selection, time split in days (modulo), modulo view mode, x-axis coordinate selection, linetype and drawing condition selection, plot cuts (zooming) in vertical direction, quality status filtering and time sign quadrats. Special layouts are thus available combining these selections.

```
                                          C

STATISTICAL REVIEW

 0 - Quit
 1 - Nearness to observations / Hour
 2 - Nearness to observations / Day
 3 - Nearness to observations / Period
 4 - Change evaluation  / Hour
 5 - Change evaluation  / Day
 6 - Change evaluation  / Period
 7 - Means
 8 - Correlation
```

STATISTICAL REVIEW (C) is an useful tool to see how well the measured output corresponds to the measurements, how much the values differ from the base run and how reliable the comparisons are. The nearness to observations is the R.M.S value of the difference between calculations and observations. Hourly and daily values include the substraction of the period mean value (to better measure the shape-fit of the run i.e. the correlation) and the period value is the mean of calculated values minus the mean of measured values. Change evaluation gives the differences between current and base calculations.

The statistics in the model offer several opportunities. It is possible to study averages for days or for running period, select hour ranges or use status information in statistical calculations or study soil/land-use class specific results (areal). Time samples are available by selecting different start and end times and hour ranges. Moreover, a specific daily hour may be studied. Standard deviations are available for hourly and daily values and for the running period. Correlations are available for hourly and daly values. Change evaluation and nearness to observations can be calculated for hours, days and for the running periods.

D

GRAPHICAL REVIEW / VARIATIONS

SELECT plot of:

0 - Quit	99 - Change mode
1 = Ebal / canopy+ground	4 = Ta&Ts&Tgave&T2
11 = Ebal / canopy	41 = Ta/TZ
12 = Ebal / ground	42 = TF
20 = Sglob	43 = Ts/Tem
21 = Et/lebow	44 = Tgave
22 = Rn	45 = T2
23 = G	46 = Taf-Ta
24 = H	47 = LAI
25 = Et,lev2,leg2	48 = hc
26 = rain	49 = alb
27 = RHz	50 = glg & gl2
28 = Uz	51 = wg & w2
29 = Precip	
31 = ELIMWG	52 = Pfg & Pf2
32 = ELIM1,ELIM3	53 = dew*1000
33 = DIF1,DIF3	54 = alfa
34 = DIF	55 = RSTO

GRAPHICAL REVIEW (D) shows the graphical representation of the last run including the base run and the deviation between them. Especially during parameter changes or in the manual mode it is used like menu B but has the advantage that also the base run is visible.

E

WRITE RESULTS (one run)

0 - Quit
1 - Create a base parameter file
2 - Write variables to a file
3 - Create a run report
4 - Write an article base

WRITING RESULTS (E) is the preferred tool to store results of periods less than 201 days. There are several alternatives for writing the results. For longer time-periods, a quickstore file for days or hours can be obtained by selecting (1,7,9,7) in MANUAL mode menu.

G

Areal mode pixels

0 - QUIT
1 - One pixel
2 - All pixels

AREAL MODE PIXELS (G) may be used when the atmospheric map databases or land use data on maps are used.

L

GRAPHICAL REVIEW / EVALUATIONS

0= Quit
1 = Select one variable/all parameters evaluation
2 = Select all variables/one parameter evaluation
99= Change plot mode

GRAPHICAL REVIEW/EVALUATIONS (L) is used in the fixed variation mode to see how much a change in the input parameter affects the output variable. Two modes are available: the effect of selected input parameters on a certain calculated variable or the effect of one input parameter on all calculated variables. The graphics for results are available for hourly, daily and period level using the plot change selection.

H

RUN VARIATIONS/VARIATION MODE

0 - Quit
1 - Fixed shift mode
2 - Spectrum mode
3 - Table mode

RUN VARIATIONS/VARIATION MODE (H) may be used to select variations either in the fixed mode, the spectrum mode or in the table mode. The modes have been explained above.

J

GRAPHICAL REVIEW / SPECTRUM

SELECT:

0= Quit
1 = Plot variation spectrum
2 = Plot variable tracking
99= Change plot mode

GRAPHICAL REVIW/SPECTRUM (J) tool is used to visualize the difference between calculations and observations. It is available for hourly, daily and period levels.

N

WRITE RESULTS (variation)

0 - Quit
1 - Write base parameters
2 - Write variations to a file

Variation results may be written into a file. Base parameter and variation result files are available.

M

Write table variation results

SELECT visible variables (-1=Ready,-2=Quit):

0-130 variables to select

WRITE TABLE VARIATION RESULTS (M) is used to write to a table the differences of average value of the output variable from the base run value during a selected period.

F

MSDOS - UTILITY SELECTION

1 - Edit a file
2 - Editor
3 - MSDOS-command prompt
4 - EQUATION pickup
5 - NAME pickup
6 - ASCII-File view
7 - Function calculator
8 - Model instructions

MSDOS - UTILITY SELECTION (F) gives chance to change to a MSDOS window.

4.3 Necessary and optional input files

Nine input files are needed to run the model (SFAREA.PXL is optional). Appendix F shows examples of the files.

COEFname.DAT:	Default parameter file a(60). Name is given in SFSTE.DAT.
COEFBETA.DAT:	Default parameter values, table b(60).
nameatm.DAT:	Atmospheric input file data. Name is given in SFSTE.DAT.
nameveg.DAT:	Vegetation file: local observations of *LAI, h,* a_f. Name is given in SFSTE.DAT.
SF2SB.EXE:	Executable file to run ASTIM. No need to change.
SFFLA.DAT:	Fixed variation mode default flags. For selecting variables for fixed variation mode.
SFTBL.DAT:	List of parameter number and change in percentage. Every line equals one run for parameter change.
SFCHG.DAT:	Changes from the default coefficients / change for new base-run setup. Name selected in the steer-file.
SFSTE.DAT:	Program steering file including directory path and file name, default output device, run time, soil type, SFCHG.DAT file name, default path, atmospheric and vegetation input file names.
SFAREA.PXL:	Description file for areal data, includes soil/land-use class list with frequencies for all classes within each pixel.

For line-based graphics a characterset (LETTER.DAT) is needed. MANUAL.TXT includes instructions to run the model. The Fortran source code is in the following two files, SFSB.FOR, SF2SB.FOR.

4.4 Modelling in detail

The following is a 'quick quide' of the ASTIM model. See also Appendix C for the example input and steering files. Only a single keystroke is usually required to select an option. E.g. for file names a <RETURN> keystroke is necessary at the end. In the following list (L.n), L describes the topic L and n the order number (e.g. E equals estimation, T equals testing etc.).

First one creates an atmopheric input file (see I.1 below), estimates the parameters in files: COEFname.dat, SFCHG.DAT and COEFBETA.dat (see I.2 below), and runs the model once R.1, stores the run results S.1 and starts to estimate the effect of the parameter change on the results E.n.

Sometimes it is useful to represent the variables as time series data (T.1), sometimes the correlation plots are preferred (T.2). The overlay plots (T.3) represent the daily development of a variable. Occasionally, the output for every hour (T.4) is needed, but daily averages (T.4) or even period averages (T.4) may be sufficient for verification information. In some cases, the difference from the base run is important (T.7), sometimes correlations between observed and calculated variables (T.5) or correlations between calculated values (T.6) are important. All these are available at the manual mode. One can also manually change the parameters and compare the output of separate runs.

The model may also be used to estimate the areal evaporation in a setup of interpolated atmospheric input (from the weather observations grid). The soil and vegetation parameters are estimated from the satellite-based land-use maps (see R.).

In the AUTO-VARIATION-mode the sensitivity analysis of the model is available. The user may be interested in knowing which parameters affect a certain calculated variable (E.21), or on which variables a certain parameter does have an effect (E.22). It may also be examined how the results change when a certain parameter is changed (E.23), or how a change of parameters will change the minimum of an output variable (E.23) or does a certain change of parameters make the model fit the observations better (E.24). The results can be stored and presented as they were in the manual mode. In the auto-variation mode the graphics can also be represented in ASCII form by a switch 1,6, see T.8.

4.4.1 Input data

I.1 The atmospheric input file is named in SFSTE.DAT (see chapter 4.3). Usually this file is based on measurements or generated by using climate scenario data. If the data is given as daily average values, the first character in ATM.DAT has to be A. If hourly based observations are used, the file ATMH.DAT is used (see Appendix B for the variables).

I.2 The parameter files are also named in the steering file, while the changes of these defaults are taken from another file (see chapter 4.3). These together give the parameter values used in the base run. Default parameters can also be changed in the menu A. Vegetation properties may be changed directly in another file (see chapter 4.3). Default classes may be selected from menu A selecting 1 for base parameter changes and writing a class number to the corresponding field. A '+' sign will appear, if parameters are further changed.

4.4.2 Running the model

R.1 To run the model after the base run, which was automatically done as the model was started (SF2SB.EXE) , the MANUAL MODE menu with selection 2 is available. Before running the model, the user can change the parameters, the flags and the variables from the menu A (1,*).

R.2 A run of the model with AUTO-VARIATION MENU can be made by using option 2. From the variation mode option, the user can select 1 to run the fixed mode variations or 2 to run the variation spectrum or 3 to run the table variation. In the fixed mode, the run will display which variable it is currently variating, after having asked whether it should change the default variation percentage. In the spectrum mode, the user may change the grid (answer 0,0 if no change). After that the user shall choose either the absolute value 'ABS mode' or the percentage change '% mode'. After this the spectrum variations are run. In the table variation mode, program runs through the variations selected in input table (file). To study the results of fixed mode variations, see E.2,E.21,E.22, for the spectrum results see E.23,E.24. Table variations may be written to a file selecting (6,*) in AUTO-VARIATION menu.

R.3 For an areal run, the time period and other run defaults are selected from menu A by selecting 7. Then, from MANUAL menu, option 8 is selected for areal use of the model. The user can then run either one pixel (select 1) from areal SFAREA.PXL file or selected pixels (select first all pixels, 2). Then the program asks the name of the areal landuse file (SFAREA.PXL), the name of atmospheric input file (ATM.DAT), the pixels to be selected, the variable to be tracked (time series are stored). Then the calculation mode is selected: (M)ain class or (A)ll classes included and further the output mode: (W)eighted results, (A)ll classes to files or (O)nly in memory to view. If all classes are selected, also the class range can be selected. Finally, the type of directory handling is selected; usually option '(L)eave them as they are' is preferred. The model then calculates the results for all selected classes for a time period selected in menu A (selecting 7 and 7,8).

4.4.3 Storing the data

S.1 For storing the results of a run there are three choices. The first one is to store the statistical results by changing the statistics output from the manual mode (1,4). The second choice is to change the graphical output from the manual mode (1,3) and then use the manual mode options 3or 4 to plot the graphics or the statistics. The third possibility is to select 6 from the manual mode and then write the used parameters (option=1), a set of variables when the selectected variables have to be picked up (2), a run report (3) or an article base (4). See T.x to change the plotting parameters. The first base run is automatically stored into the files.

S.2 The storing of the results of a auto-variation run is done in a similar to that in the manual mode, selecting 1,4 or 1,3 from the auto-variation menu and then storing the run results by selecting 3,4 or 5 from the same menu. Also selection 6 with a filename is available for table variation results. Storing the variation runs to files is also available.

4.4.4 Estimating and testing

E.1 An estimation of the change of the results of one run (from a base run) is available at the manual mode menu. Selecting 5 one can view the changes as in the selection 3 except that the base run reference values are included when clearly representable. Also selecting 3 and Combination plot sums by selecting (L)ist and (G)roup, (C)ombine, are available.

E.2 For estimating the auto-variation changes there are two types of graphical plots available: selection 3 (show spectrum) for the spectrum mode and selection 4 (show evaluations) for the fixed mode. See E.3-6 for their usage.

E.3 Fixed mode estimation of input parameters. To find out which parameters from a certain set are important to a certain calculated variable and which are not, the fixed variation mode from the auto-variation menu may be picked up by selecting 2,1. After the run, the evaluations can be seen by selecting 5,1 from the auto-variation mode. The pro- gram then allows the user to select which calculated variable is evaluated.

E.4 Fixed mode estimation of calculated variables. To find out the variables a certain parameter has an effect on, one can do like in E.3, but for the plots use selection 5,2 instead of 5,1.

E.5 Spectrum mode estimation running and viewing auto-variation results. For examining, how the results and the goodness of the fit change when a certain parameter is changed, the spectrum mode is an useful tool. It is used by selecting 2,2 from the auto-variation menu, answering the questions and after the run selecting 3 and the variable.

E.6 Spectrum mode optimisation.To examine if a certain change of parameters makes the model fit better to observations one can use the spectrum mode from the auto-variations menu. First run and store the results of the base run variations, see R.2,S.2, and then change the base parameters from 1,1. Then the user can run the same variations and study the change of the minimum point of the model/parameters like in E.5.

4.4.5 Time series and plotting

T.1 Time series view. To select the normal time-series (the default) all one is to do is to check that the 'respect variable' is time in the change plot parameters -menu (,99). Hour/day/pickup switch is also available and one can see the period in several pictures using the modulo-time and selecting STOP as the modulo mode.

T.2 Correlation plot view. To make a correlation plot one can change the 'respect variable' in the change plot parameters -menu and plot any of the output variables as the function of it. Hour/day/pickup switch is available as well as the plot cuts. To see observations separately from the calculated variables SEPA-mode can be chosen, otherwise COMP-mode is useful to compare exact correlations to simulated correlations. Modulo mode can be used to split the period to several pictures (use STOP).

T.3 Overlay plots are available at the modulo mode in the change plot parameters -menu. The modulo time can be given and the mode CONT selected instead of STOP. Then the time is split and the (daily) variation of the output parameter is plotted on the same figure showing the modulus of the time at the x-coordinate.

T.4 Time step selection and quality status filtering. Hour/Day/Period is selected either directly in the current menu (statistics, spectrum view) or from the change plot parameters -menu. For hours and days the results include the period average substraction, and for the period the result is usually the difference of the observed and calculated period means. Statistics includes only those hours, during which the measured values have been classified as *acceptable value*, selected by (1,*) in the main menu. Possible status values are:
0 = Missing information
1 = Acceptable value
2 = Erroneous value
3 = Unreliable value due to weather etc. conditions

T.5 The correlation between an observed variable and a calculated variable in the one-run mode can be studied by selecting the variable from the *change plot parameters* -menu after selecting 3,99. Then any of the output variables can be plotted as a function of it (see T.2).

T.6 The correlation between a recently calculated variable and a calculated base variable in the one-run mode can be studied by selecting the variable from the *change plot parameters* - menu after selecting 5,99. Then any of the output variables can be plotted as a function of it (see T.2).

T.7 The changes of calculated variables from the base run can be studied by selecting 5 from the manual mode and select any of the output modes from the *change plot parameters* -menu.

T.8 Sometimes numerical values are preferred instead of graphics when presenting the results. In the manual mode they can be obtained by selecting 6.

T.9 Sometimes there is a need to plot a simple addition and/or substraction of a set of variables. To plot an addition or a substraction of a collection of variables COMBINATION should be selected within the *graphics plotting* menu. By selecting (L)ist, a numbered variable list appears. For a (+)-sign the number is selected once, for a (-)-sign twice. Three times makes the variable to be excluded. When the selections are ready, -1 is given for plotting, -2 to quit. An empty line equals selection 0 (zero).

T.10 Quite often a function of the variables may give a better idea about the existing (cor)relations, so the possibility to define the axis as functions of them is included. It can be selected from the graphics plotting as FUNCTION to plot. Another way to define a simple function of the variables is
to select it from the same menu as a COMBINATION and then select (F)unction. What appears is a line which will include (x,y)-function set references for one or more figures i.e it is possible to plot several functions per figure and also possible to divide the screen into several subscreens where each subscreen includes one figure.

4.4.6 Statistics

T.11 Sometimes there is a need to plot averaged, Fourier transformed, Fourier filtered or accumulated values of a variable. To plot one of these alternatives COMBINATION within the graphics plotting menu should be selected. Then (L)ist is selected and a numbered variable list appears. After selecting the variables the next choice is -1 (to plot) or -2 (to quit). An empty line equals selection 0 (zero). If all selected variables are to be treated the next selection is (G), if not, then (I). Now the mode in which the variable is to be treated can be chosen. When the questions have been answered, the plotting begins. The plot will show selected results according to the mode chosen from the list. The following alternatives are available:

(T) = Standard deviation
(F) = Fourier transform
(L) = Fourier transform with filtering
(W) = Fourier backtransform with filtering
(B) = Fourier+backtransform
(A) = Fourier averaging
(N) = Averaging
(C) = Combine (defining Group mode)
(U) = Accumulated values
(P) = Plot separate (default)

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Appendix A: Combined soil land-use classification.

Table 1. Combined soil/land-use classification used in the ASTIM model.

Land use class	Soil class	Class number
Clouds and cloud shadows		1
Water		7
Fields and treeless areas on heathlands	B,C, D, E, F*	11, 12, 13, 14, 15
Bare mountain regions and tundra		2
Rocks and urban areas		3
Peat production areas		4
Open bogs		5
Sparce forests	B, C, D, E, F*	21, 22, 23, 24, 25
Spruce swamps, 0-50 m^3ha^{-1}		31
Spruce swamps, 51-150 m^3ha^{-1}		32
Spruce swamps, >150 m^3ha^{-1}		33
Pine swamps, 0-50 m^3ha^{-1}		34
Pine swamps, 51-150 m^3ha^{-1}		35
Pine swamps, >150 m^3ha^{-1}		36
Pine and spruce forests, 0-50 m^3ha^{-1}	B, C, D, E, F*	41, 42, 43, 44
Pine and spruce forests, 51-150 m^3ha^{-1}	B, C, D, E, F*	45, 46, 47, 48
Pine and spruce forests, > 150 m^3ha^{-1}	B, C, D, E, F*	49, 50, 51, 52
Deciduous forests, 0-50 m^3ha^{-1}	B, C, D, E, F*	61, 62, 63, 64
Deciduous forests, 51-150 m^3ha^{-1}	B, C, D, E, F*	65, 66, 67, 68
Deciduous forests, > 150 m^3ha^{-1}	B, C, D, E, F*	69, 70, 71, 72
Mixed forests, 0-50 m^3ha^{-1}	B, C, D, E, F*	81, 82, 83, 84
Mixed forests, 51-150 m^3ha^{-1}	B, C, D, E, F*	85, 86, 87, 88
Mixed forests, > 150 m^3ha^{-1}	B, C, D, E, F*	89, 90, 91, 92
		Total **58 classes**

* B= rock plateaus, C=till, D=gravel and sand, E=peat, F=silt and clay.

Soil class is defined as a combination of two soil maps, one of 1:100000 including 20 classes and one of 1:1000000 including 12 classes. The combination was made at Finnish Environment Institute.

Appendix B: Input variables.

Number	Variable	Unit	Explanation
1	T_a	°C	Air temperature
2	ua	ms^{-1}	Wind speed
3	Rha	%	Relative humidity
4	S	Wm^{-2}	Global incoming shortwave radiation
5	rainfall	$mmday^{-1}$	Rainfall (water and snow)
6	LE	Wm^{-2}	Evapotranspiration
7	R_n	Wm^{-2}	Net radiation
8	T_g	°C	Average soil temperature, 0-10 cm
9	T_s	°C	Surface radiation temperature
10	G	Wm^{-2}	Ground heat flux
11	H	Wm^{-2}	Sensible heat flux

Variables 6-11 are used only to compare calculations to observations.

Appendix C: Model parameters (table a).

Number	Name	Value	Unit	Explanation
1	Z_1	100	mm	depth of the surface layer
2	Z_2	1200	mm	depth of the bottom layer
3	w_{wilt}	0.10	%	wilting point (if measured, otherwise a(30))
4*				
5	w_{sat}	0.55	%	maximum soil moisture content (if measured, otherwise *a(6))*
6	w_s	0.57	%	porosity according to COSBY
7	ψ_s	-0.0531	m	saturation suction according to COSBY
8	K_s	2.98E-6	ms^{-1}	saturated hydraulic conductivity according to COSBY
9	b	11.55		a constant depending on soil type by COSBY
10	w_g	0.25	m^3m^{-3}	initial moisture content in layer 1
11	w_2	0.40	m^3m^{-3}	initial moisture content in layer 2
12	t_2	289	°K	initial soil temperature at depth 2
13	const	3.54		$2\pi^{1/2}$ in Eq. (7)
14	const	0.00175		$2\pi/(60*60)$ in Eq. (7)
15	const	4180000	$J\,°C^{-1}m^{-3}$	in calculating ρc by Eq. (78)
16	const	0.3		constant in Eq. (78)
17-18*				
19	const	0.60		constant in Eq. (13)
20	const	0.05		constant in Eq. (13)
21	ε_g	0.98		emissivity of the soil
22	ε_f	0.98		emissivity of the vegetation
23	α	0.150		in Eq. (24)
24	β	0.05		in Eq. (24)
25	a	-0.198		in Eq. (76)
26	b	1.3889		in Eq. (76)
27	const	0.4		constant in Eq. (41)
28	const	0.5		constant in Eq. (52)
29	const	8		constant in Eq. (52)
30	w_{wiltc}	0.10	m^3m^{-3}	wilting point given by COSBY

Number	Name	Value	Unit	Explanation
31	z_0	0.01		roughness of bare soil in Eq. (53)
32	const	3.0		constant in Eq. (53)
33	const	0.66		constant in Eq. (53)
34	fgw	1.00		portion of rain leftover puddle flowing to runoff in a time step
35	const	1.24		constant in Eq. (45)
36	const	-0.143		constant in Eq. (45)
37	fgg0	1.0		plant dependent water uptake factor (layer1)
38	const	9.4		constant in Eqs.(36 and 37)
39	α_{fg}	0.6477		plant dependent water uptake exponent(layer1)
40	const	9		constant in Eq. (49)
41	const	28		constant in Eq. (61)
42	beta	1.1		β in Eqs. 49 and (61)
43	S_{max}	800	Wm^{-2}	in RST calculations, Eq. (68)
44	S_0	1	Wm^{-2}	in Eq. (68)
45	RS_{min}	45	sm^{-1}	in Eq. (68) , the minimum stomatal resistance
46	a			Soil parametrisation for suction and hydraulic conductivity according to Abramopoulos (see Table 3) ψ = -exp(A/w + B + C*w + D*w**2) K = exp(a/w + b + c*w + d*w**2) D = K * d(ψ)/d(w)
47	b			
48	c			
49	d			
50	A			
51	B			
52	C			
53	D			
54	$w_{s,ab}$	0.56	m^3m^{-3}	porosity for Abramopoulos classification
55	$w_{max,ab}$	0.55	m^3m^{-3}	w_{max} if measured, othervise a(54)
56	z_a	2.0	m	measurement height
57	α_{exp}	4.0		Noilham temperature dependence, plant dependent
58	Ta_{msum}	1800.0	°C	maximum temperature sum default
59	S_{msum}	1.95e9	Jm^{-2}	maximum radiation sum default
60	A_S	0.93		vegetation cover correction for SGSUM used in calculations of plant development

* old parameters; not any more used, but still in the parameter file

Appendix C: Model parameters (table b).

Number	Name	Unit	Explanation
1	LAI_0	m^2m^{-2}	green LAI amplitude
2	$t_{1,LAI}$	days	green LAI start of growth
3	α_{LAI}		green LAI growth factor 1
4	$t_{2,LAI}$	days	green LAI end of growth
5	β_{LAI}		green LAI growth factor 2
6	$DLAI_0$	m^2m^{-2}	dry LAI amplitude
7	$t_{1,DLAI}$	days	dry LAI start of growth
8	α_{DLAI}		dry LAI growth factor 1
9	$t_{2,DLAI}$	days	dry LAI end of growth
10	β_{LAI}		dry LAI growth factor 2
11	$H_0/DLAI_0$	$m/(m^2m^{-2})$	height vs. DLAI ratio
12	a_g		vegetation albedo
13	RR_0	Wm^{-2}	Lohammar half value resistance net radiation limit
15	RS_{max}	sm^{-1}	maximum stomatal resistance
16	$SGRN_{rat}$	Wm^{-2}	(Sg/Rn)-ratio
17	SOL_o	Wm^{-2}	Lohammar half value resistance global radiation limit
18	CND_o	ms^{-1}	Lohammar max conductivity: a(45) used
19	CDFE	1/mbar	Lohammar water vapour deficit (1/½-value) coefficient
20	s_R	$1/(Wm^{-2})$	Avissar, radiation ½-value slope
21	b_R		Avissar, radiation ½-value value
22	s_T	1/°C	Avissar, temperature maximum ½-value slope
23	b_T	°°C	Avissar, temperature maximum ½-value value
24	s_C	1/°°C	Avissar, temperature minimum ½-value slope
25	b_C	°°C	Avissar, temperature minimum ½-value value
26	s_V	1/mbar	Avissar, water vapour deficit ½-value slope
27	b_V	mbar	Avissar, water vapour deficit ½-value value
28	s_{wg}		Avissar, soil moisture ½-value slope
29	b_{wg}		Avissar, soil moisture ½-value value
30	$weigh_{wilt}$		soil moisture weighting factors (Deardorff)
31	$weigh_{w2}$		

Number	Name	Unit	Explanation
32	$weigh_{wg}$		
33	SGL_{Noil}	Wm^{-2}	Noilham radiation part coefficient
34	FCF_{Noil}		Noilham radiation part coefficient
35	$Defw_{Noil}$		Noilham water vapour deficit coefficient
36	Dfw_{lim}		Noilham water vapour deficit coefficient
37	T_{opti}	°C	optimum temperature (Noilham)
38	F_{rndm}		RSTO randomize factor (relative change)
39	CF_{DEWM}		maximum dew store factor
40	au		wind factor in Eq. (88)
41	$DEWMS_{RAT}$		Ratio of maximum interception storage capacities of snow and water
42	wg_{F0}		Initial soil frost, layer 1
43	$w2_{F0}$		Initial soil frost, layer 2
44	ws_{F0}		Initial surface snow water equivalent
45	R_{0snow}	sm^{-1}	Relative surface resistance of snow
46	Rs_{α}		Snow amount influence on surface resistance
47	Mc_{snow}		Snow melting rate factor
48	FC_F		Frost freezing rate coefficient
49	α_{MT}		Frost melting rate temperature dependence
50	α_{FT}		Frost freezing rate temperature dependence
51	α_{FMz}		Snow amount dependence of snow melting rate
52	$MF_{0,snow}$		Rate of snow melting and freezing
53	LAI_{scale}		LAI,DLAI scaling factor
54	$DPDS_{wind}$		Interception snow wind and time dependency
55	$SNOW_{DPFR}$		Interception snow wind and time dependency
56	$DPDW_{wind}$		-”- water -”-
57	$WATR_{DPDR}$		-”- water -”-

Appendix D: Output variables.

Number	Name	Unit	Explanation
1	T_a	°C	temperature at above-canopy level
2	T_s	°C	surface radiation temperature
3	T_f	°C	vegetation temperature
4	T_g	°C	average soil temperature 0-10cm
5	T_2	°C	average soil temperature 0-120cm
6	T_f-T_a	°C	temperature difference, T_f - T_a
7	T_{af}-T_a	°C	temperature difference, T_{af}-T_a
8	T_g-T_a	°C	temperature difference, T_g-T_a
9	T_s-T_a	°C	temperature difference, T_s-T_a
10	R_n	Wm^{-2}	net radiation
11	H	Wm^{-2}	sensible heat
12	LE	Wm^{-2}	latent heat flux (=evapotranspiration)
13	G	Wm^{-2}	ground heat flux
14	w_g	m^3m^{-3}	soil moisture content 0-10 cm
15	w_2	m^3m^{-3}	soil moisture content 0-120 cm
16	dew	mm	dew*1000
17	RST	sm^{-1}	canopy stomatal resistance
18	D	m^2s^{-1}	diffusivity / used in model runs
19	LE_f	Wm^{-2}	evaporation from the vegetation
20	LE_g	Wm^{-2}	evaporation from the ground
21	α		MIN(E_{lim}/E_{pot},1.) - limiting factor
22	E_{lim2}	Wm^{-2}	limiting evaporation / method 2
23	E_{lim1}	Wm^{-2}	limiting evaporation / method 1
24	D_2	m^2s^{-1}	diffusivity / method 2
25	D_1	m^2s^{-1}	diffusivity / method 1
26	E_{lim}	Wm^{-2}	Limiting evaporation / used in model runs
27	λ_g	Wm^{-1} °K^{-1}	ground heat conductivity / 0-10cm
28	λ_2	Wm^{-1} °K^{-1}	ground heat conductivity / 0-120cm
30	S	Wm^{-2}	global incoming shortwave radiation
31	Rs_f	Wm^{-2}	shortwave net radiation to the canopy

Number	Name	Unit	Explanation
32	Rs_g	Wm^{-2}	shortwave net radiation to the soil surface
33	R_s	Wm^{-2}	total shortwave net radiation = Rs_f+Rs_g
34	R_a	Wm^{-2}	incoming atmospheric longwave radiation
35	Rl_f	Wm^{-2}	longwave net radiation to the canopy
36	Rl_g	Wm^{-2}	longwave net radiat. to the ground surface
37	Rl	Wm^{-2}	total longwave net radiation = $Rl_f + Rl_g$
38	R_S	Wm^{-2}	electromagnetic radiation
39	Pf_g		pF-value of the soil 0-10cm
40	Pf_2		pF-value of the soil 0-120cm
41	Evag	$mms^{-1}m^{-2}$	evapotranspiration from ground surface (=$Le_g/\lambda(T_g)$)
42	q_a	mbar	air water vapour pressure
43	q_{af}	mbar	air water vapour pressure in vegetation
44	q_f	mbar	air water vapour pressure at plant surface
45	q_s	mbar	air water vapour pressure at soil surface
46	λEtr	$mms^{-1}m^{-2}$	plant transpiration
47	RF_{srad}		vegetation evapotranspiration response to radiation
48	RF_{wg}		vegetation evapotranspiration response to soil moisture
49	RF_{wvdef}		vegetation evapotranspiration response to air water vapour pressure deficit
50	RF_{Temp}		vegetation evapotranspiration response to temperature
51	a_g		soil albedo
52	a_f		vegetation albedo
53	σ_f		shielding factor
54	σ_{ua}		wind factor
55	σ_α		coupling factor for momentum transfer
56	LAI	m^2m^{-2}	green leaf area index
57	DLAI	m^2m^{-2}	total (dry) leaf area index
58	h	m	vegetation height
59	uptake	mms^{-1}	water uptake to surface layer
60	Runoff	mms^{-1}	runoff

Number	Name	Unit	Explanation
61	ρc_g	$JK^{-1}m^{-3}$	Soil surface heat capacity
62	ρc_2	$J\,^{\circ}K^{-1}m^{-3}$	Root layer heat capacity
63	EPOT1	Wm^{-2}	potential evapotranspiration (Penman)
64	EPOT2	Wm^{-2}	potential evapotranspiration (lake)
65	EPOT3	Wm^{-2}	potential evapotranspiration (Deardorff)
66	$\rho c_p C_{gh}$	$Wm^{-2}\,^{\circ}K^{-1}$	in calculations of H_g and Le_g
67	$\rho c_p C_{fh}$	$Wm^{-2}\,^{\circ}K^{-1}$	in calculations of H_f and Le_f
68	R_{prim}		primary vegetation evapotranspiration conductivity
69	R_{sec}		secondary vegetation evapotranspiration conductivity (without dew and interception)
70	snow	mm/hr	snowfall
71	AF_{snow}	mm	accumulated snowfall left on surface
72	wg_F	m^3m^{-3}	soil surface layer frost
73	$w2_F$	m^3m^{-3}	soil root layer frost
74	ws_F	m^3m^{-3}	snow water equivalent
75	Pr_w	mms^{-1}	Precipitation, water
76	Pr_s	mms^{-1}	Precipitation, snow
77	Pr_{cs}	mm	accumulated snow precipitation
78	λ_{snow}	$Wm^{-1}\,^{\circ}K^{-1}$	snow heat conductivity
79	T_{snow}	$^{\circ\circ}C$	snow temperature
80	FI_w	mms^{-1}	rain flux into interception storage
81	Fi_s	mms^{-1}	snowflux into interception storage
82	Intercept	mm	interception (water+snow)
83	$Dropped_w$	mm	amount of water dropped
84	$Dropped_s$	mm	dropped snow
85	dew_w	mm	water dew
86	dew_S	mm	snow dew
87	Pr_{hour}	mm/hr	rainfall during last hour
88	u*	ms^{-1}	friction velocity
89	u_{af}	ms^{-1}	wind speed at reference level
90	u_a	ms^{-1}	wind speed at measurement level
91	rhgr	sm^{-1}	$1/C_{gm}$, where C_{gm} as in eq.(51)
92	rsf	sm^{-1}	snow layer addition in $1/C_{gm}$

Number	Name	Unit	Explanation
93	M_{Snow}	mms^{-1}	snow melting rate
94	M_g	mms^{-1}	soil surface layer frost melting rate
95	M_2	mms^{-1}	soil root layer frost melting rate
96	F_S	mms^{-1}	snow freezing rate
97	F_g	mms^{-1}	soil surface layer frost freezing rate
98	F_2	mms^{-1}	soil root layer frost freezing rate
99	T_{MF2}	°°C	root layer melting temperature
100	d_{gwater}	mm	water released in soil surface frost melting
101	h_{snow}	mm	snow layer depth
102	Ta_{sum}	°°C	thermal sum
103	S_{sum}	Jm^{-2}	radiation sum
104	Ta_{maxsum}	°°C	maximum of thermal sum
105	S_{maxsum}	Jm^{-2}	maximum of radiation sum
108	EVAP	$mms^{-1}m^{-2}$	evapotranspiration from plants, $Le_f/\lambda(T_f)$
109	$fr_{snowveg}$		fraction of snow in surface albedo
110	$dmax_{snow}$	mm	maximum snow dew
111	RS_{min}	sm^{-1}	minimum daily stomatal resistance
112	re_1		in q_{af} calculations
113	re_2		-”-
114	re_3		-”-
115	rc_1		in T_{af} calculations
116	rc_2		-”-
117	rc_3		-”-
118	C_{fh}	ms^{-1}	C_{fh} in Eq. (61)
119	$EPOT_{veg}$	Wm^{-2}	potential evapotranspiration from vegetation
120	$EPOT1_{veg}$	Wm^{-2}	Potential evapotranspiration from plants, Penman
121	EPOT2	Wm^{-2}	potential evapotranspiration from water
122	$EPOT3_V$	Wm^{-2}	potential evapotranspiration, modified Deardorff
123	$EPOT4_V$	Wm^{-2}	potential evapotranspiration, Deardorff
124	R_{prim0}		primary resistance corresponding to minimum stomatal resistance
125	R_{sec0}		secondary resistance corresponding to minimum stomatal resistance

Number	Name	Unit	Explanation
126	EPOT	Wm^{-2}	potential evapotranspiration from ground, used
127	EPOT4	Wm^{-2}	potential evapotranspiration from ground, Deardorff

Appendix E: Examples of the parameter files.

COEFEURA.DAT

```
100. ,1200. ,.25 ,.450 ,.614
.468 ,-0.0531 ,2.98E-06,11.55 ,.43
0.46 ,289.4 ,3.54 ,0.175E-02,.419E+07
.340 ,8. ,44. ,.600 ,0.500E-01
.980 ,.980 ,.150 ,.500E-01 , -0.198
1.3889 ,.400 ,.500 ,8.00 ,0.2290
.100E-01,3.00 ,.660 ,0.85 ,1.24
.143 ,1.00 ,9.40 ,0.6477 ,9.00
28.0 ,1.10 ,800. ,1.00 ,60.
-0.4176 ,-32.2812,12.7663 ,36.2916 ,0.3221
5.8433 ,0.8190 ,-26.1273,0.555 ,0.614
2.0 ,3.0 ,1800.0 ,1945E6 ,0.93
```

COEFBETA.DAT

```
0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
0.3 0.2 15 0.4 5e04 0.7 20 0.0125 0.07 0.010
200 -0.5 306.5 0.7036 285 -0.00205 1000 25 0.23 1.4
0.9 0.1 52.5 0.55 40 0.2 23 0.0 1.0 0.02
3.2 0.00 0.00 25. 30.0 0.1 2.8 2.8 1.2 0.7
0.002 1.2 1.0 -3.5E-4 0.7 -3.5E-4 0.8 0 0.5 3.0
```

ATM.DAT (Daily atmospheric file)

```
A Time   Temp   Temp_min   Temp_max   Wind_spd   Humidity   Sglob_day   Precipitation
1        -18.7   -18.7      -18.7       3.8        98.3       805.9397        1.1
2        -22.7   -22.7      -22.7       2.3        94.3       951.4613        0
3        -21.5   -21.5      -21.5       1.5        98.6       838.9063        0.1
4        -24.5   -24.5      -24.5       1.9        97         992.925         0
5        -25.7   -25.7      -25.7       2.3        92.3       1431.864        0
```

ATMH.DAT (Hourly atmospheric file)

```
180 1 14.56 4.628 82.70 63.965 0.000 0.000 -25.280 14.24 13.57 -8.904 -16.3762
1 1 1 1 1 0 1 1 1 1 3
 180 2 14.62 4.577 82.40 127.804 1.500 0.000 -7.990 14.11 13.75 -5.554 -2.4358
1 1 1 1 1 0 1 1 1 1 3
 180 3 14.13 4.787 88.20 135.580 0.701 0.000 -1.791 14.06 13.76 -4.426 2.6354
1 1 1 1 1 0 1 1 1 1 1
 180 4 13.36 3.215 97.20 134.950 1.197 0.000 -2.528 14.02 13.62 -3.079 0.5506
1 1 1 1 1 0 1 1 1 1 1
```

VEGET.DAT

```
Time        LAI         height      alb
1           0           0           0.22
165         0           0           0.22
171         0.51        0.18        0.22
176         2.27        0.3         0.22
179         2.68        0.39        0.22
182         2.81        0.47        0.22
185         2.97        0.56        0.22
191         3.34        0.74        0.22
194         2.57        0.81        0.22
197         1.99        0.86        0.22
203         1.05        0.88        0.22
206         0.69        0.84        0.22
209         0.42        0.74        0.22
212         0.22        0.59        0.22
215         0.1         0.36        0.22
218         0.06        0.08        0.22
221         0           0.08        0.22
260         0           0.08        0.22
260.1       0           0           0.22
365         0           0           0.22
```

SFFLA.DAT

```
0 0 0 0 0 0
0 0 1 1 1 1 1 1 1 1
1 1 0 0 1 1 1 1 1 1
1 1 1 1 0 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 0 0 0 0
```

SFTBL.DAT

```
10 0 0 0 /
10 +20 11 +20 0 0 /
10 -20 11 -20 0 0 /
12 +3.5 0 0 /
12 -3.5 0 0 /
10 0 0 0 /
 0 0 /
```

SFSTE.DAT

```
' THT:[IKONEN.PROG.SF]SFSTE.DAT'  ! Redirect steering, empty 1st char=this file
0 0 0 -1 -.5 24.5 0.3 0.5      !NRF:1..3,IOATM:-1Avg,0Re,1Use,hlimits,A_dryness,A_runoffr
'PC'                           !IO device
240 220 1.0 24.0               ! d_max d_start h_start h_end
2                              ! a(-1):
2                              ! a(-2):
'eura'                         ! Coeff-def. soil type
'SFCHG.DAT'                    ! Coeff-chg. File
'.\'                           ! Default path for IO
'vihtisaa.dat'                 ! Atmospheric file
'vihtiveg.dat'                 ! Vegetation file
4.                             ! lai, used in fixed LAI mode
1.0                            ! hau,   -"-
0.22                           ! als,   -"-
```

SFCHG.DAT

```
 1 100.  !dp1 Parameters for current SF-model run
 2 1200. !dp2
 3 0.20  !  ->  added changes to the basic set
 4 0.43  !
 5 0.45  !
10 0.24  !wg0
11 0.35  !w20
12 268.0
 0 0
```

SFAREA.PXL (a part of file)

```
X0,Y0: 3170487. 6710487. # 8000 4000 D: 25.00000 25.00000 MI,MA: 1 93,I0=MI-1 ICO: 0
 3203987. 6710987. 7 1600
 3204987. 6710987. 3 2 7 1498 12 34 50 65 66 1
 3205987. 6710987. 0 4 3 15 7 1125 12 51 13 22 22 32 23 7 46 10 47 99 50 87 66 75 70 3 90 70
 3206987. 6710987. 3 6 7 654 22 89 23 3 46 67 47 31 49 4 50 76 66 445 70 92 90 133
 3207987. 6710987. 3 4 7 4 12 2 22 219 42 32 46 25 50 324 66 361 70 461 82 25 86 43 90 100
 3208987. 6710987. 0 71 3 4 7 17 12 276 13 1 15 69 22 62 23 15 25 41 31 43 32 2 46 45 50 68 52 2
 3209987. 6710987. 0 2 3 48 7 54 12 458 22 30 25 9 46 289 50 206 52 4 70 2 86 30 90 466 92 2
 3210987. 6710987. 12 150 15 15 22 367 42 13 46 60 50 220 66 61 68 10 70 435 82 31 86 10 90 228
 3211987. 6710987. 3 13 13 26 14 17 21 98 22 200 23 91 32 13 35 5 41 19 42 85 43 5 45 1 46 142
```

Appendix F: List of additional facilities for data managment.

PXYZ.FOR - a program to view atmospheric map time series

DCOLLECT.FOR - a program to manage and utilize map time series files

VH.FOR - soil type characteristics

VAVE.FOR - a program to collect class results for each variabe

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Monistesarja

Toimeksiantaja
-

Toimielimen asettamispvm
-

Julkaisun osat
Mallin teoria, tekninen manuaali ja liittteet

Tiivistelmä
Tämä raportti sisältää maaperä/kasvi/ilmakehä mallin (ASTIM - **A**real **S**urface **T**ransfer **I**nterface **M**odel) teoreettisen kuvauksen sekä mallin käyttöohjeet. Mallilla voidaan laskea maan pinnan energiataseen, maankosteuden ja lämpötilan vaihteluja eri kasvillisuusalustoilla. Lähtötietoina tarvitaan havaintoja päivittäisestä sadannasta, lämpötilasta, ilman kosteudesta, tuulen nopeudesta ja lyhytaaltoisesta säteilystä. Haihdunta voidaan laskea joko maastotyypeittäin tai arvioida keskimääräinen aluehaihdunta (esim. vesistöalueelle) painottaen maastotyyppejä niiden todellisen peittävyyden mukaisesti. ASTIM on alustavasti parametrisoitu 58 maaperä/kasvillisuusalustalle ja se tuottaa yli 120 tulostetta. Käytännössä mallin laskentamenetelmien verifiointi on haihdunnan osalta vaikeaa, koska haihduntatietoa on niukasti saatavilla. Yksittäisiltä viljapelloilta on olemassa kasvukauden kattavaa haihduntadataa. Alueellisella tasolla mallia voidaan verifioida vesitasemenetelmän avulla. Projektin rahoitti EU/LIFE-rahasto (Financial Instrument fot the Environment).

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Abstract
The report presents the theoretical description and the user manual of the Areal Surface Transfer Interface Model ASTIM. ASTIM is a one-dimensional soil/vegetation/atmosphere energy transfer model, designed to calculate surface fluxes, temperatures and soil moistures, i.e. to model surface conditions and energy exchange from synoptic weather observations. Daily atmospheric data; air temperature, precipitation, relative humidity of air, wind speed and global shortway radiation are needed to run the program.ASTIM calculates 125 output variables for different soil/land-use types and areally weighted fractions may be selected (i.e. a mean evapotranspiration rate over the whole drainage basin). Initial parameterisation for 58 soil/land-use classes are included in the model. Measured soil moisture, evapotranspiration, or temperature data can be used to compare the model output, for example with local observations of soil moisture content or evapotraspiration and with water balance data.In practice, the verification will turn out to be difficult for all the soil/land-use classes because of the scarcity of the data. The project was financed by the Finacial Instrument for the Environment (LIFE) of the EU.

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